NOAA Technical Memorandum NOS OR&R 42

Deepwater Horizon Oil Spill: Salt Marsh Oiling Conditions, Treatment Testing, and Treatment History in Northern Barataria Bay, Louisiana (Interim Report October 2011)

Seattle, Washington
April 2013

DEPARTMENT OF COMMERCE • National Oceanic and Atmospheric Administration (NOAA)
National Ocean Service • Office of Response and Restoration

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NOAA Office of Response and Restoration
7600 Sand Point Way NE
Seattle, WA 98115

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DEPARTMENT OF COMMERCE

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Executive Summary

The *Deepwater Horizon* oil spill resulted in heavy oiling conditions in the salt marshes of Northern Barataria Bay, including portions of Bay Jimmy, Bay Batiste, Wilkinson Bay, St. Mary's Point, and vicinity. Following source control and the completion of nearshore on-water recovery and bulk oil removal from many shoreline areas, persistent oiling conditions in the marshes of Northern Barataria Bay included heavily oiled vegetation mats and wrack lines that in some cases overlaid a thick layer of emulsified oil (mousse) on the marsh substrate. Much of the mousse layer averaged 2-3 centimeters (cm) in thickness and did not appear to be weathering or naturally degrading over time. Under maximum oiling conditions, 49 kilometers (km) (31 miles) of heavily oiled marsh shorelines were documented in Northern Barataria Bay.

Due to the degree and nature of persistent oiling, traditional marsh treatment methods, including low-pressure flushing, vacuum treatments, use of sorbents, and natural attenuation, did not appear to be effective for the most heavily oiled shorelines. In addition, there was concern that long-term oiled marsh recovery over large areas could be at risk without some form of effective intervention. There was also the significant competing concern that aggressive cleanup in the marshes could cause further damage, delaying or limiting oiled marsh recovery, as has often been observed following many previous oil spills. Due to these factors, a series of marsh treatment field tests was conducted followed by periodic monitoring.

The initial treatment tests and short-term monitoring ruled out several potential treatments and combinations of treatments, and even supported the cancellation of some on-going operational treatments, due to ineffectiveness and potential damage to the marsh. A second round of adaptive treatment tests followed by short-term monitoring indicated that a combination of raking and cutting effectively removed the oiled vegetation mats and wrack, reduced the mousse layer, and resulted in the predominance of weathered surface oil residue, rather than mousse, on the marsh surface; without obvious detrimental effects to the marsh.

Longer-term monitoring confirmed the changes in oiling conditions observed over the short term, and also indicated that the raking and cutting treatments aided the early stages of marsh vegetation recovery, as well as initial recovery for some marsh fauna such as fiddler crabs, as compared to the other treatments and natural recovery (no treatment). In addition, sediment sampling indicated that oil was not mixed into the underlying sediments as a result of treatment, as has frequently been observed during past oil spills. Sediment sampling also showed evidence that the vegetation raking and cutting treatments improved the rate of oil weathering in the marsh sediments, as compared to the other treatments and natural recovery. Longer-term monitoring also indicated that storm-driven oil re-mobilization and subsequent marsh oiling were minimized for the treatment areas, as compared to natural recovery.

The treatment tests and short-term monitoring results were used to develop an operational-scale Shoreline Treatment Recommendation (STR) based primarily on vegetation raking and cutting (STR S3-045). STR S3-045 was implemented to completion over a seven-month period, with various adaptive revisions based on continued monitoring (including the treatment-test set asides). STR treatments included manual and combined mechanical-manual approaches. All manual work on the marsh was conducted from walk boards, to limit further marsh damage. All STR treatments were conducted in the presence of SCAT/agency field advisors-monitors, to maximize treatment effectiveness and minimize marsh damage. Roughly 24 km (15 miles) of marsh shorelines were identified for potential treatment; 11 km (7 miles) of marsh shorelines were ultimately treated. 6,429 cubic yards and 536 tons (1,072,000 lbs) of oil and oiled vegetation/debris were removed during cleanup operations. All marsh shorelines under the STR were inspected and met STR-specific No Further Treatment (NFT) guidelines. A follow-on patrol and maintenance STR (STR S4-032) was developed and is still active as of the date of this report.

Recommended future actions include: 1) continued review of STR S4-032 patrol and maintenance reports from Operations and LDEQ; 2) Shoreline Clean-up Completion Plan (SCCP) surveys and inspections and/or post-hurricane season SCAT surveys and field reconnaissance to be conducted in November-December 2011 for all STR S4-032 zones, segments, and adjacent areas, as appropriate, to determine the need for any further treatment; and 3) retention of set-asides for continued monitoring and research to evaluate oiling conditions, treatment alternatives, cleanup response, habitat recovery, and restoration measures over the longer term, contributing to a better understanding of this event and enhancing response and restoration capabilities for future spills.

Priority areas for upcoming SCAT surveys and field reconnaissance would include locations that were the most heavily oiled (STR Zones B, G, H, I, J, K, and N), as well as any current set-aside sites that will not be retained for future monitoring and research. Any further intensive treatments (e.g., raking and cutting) should be limited to areas where such treatment would be needed for long-term marsh recovery and restoration, taking net environmental benefit and “as low as reasonably practicable” oiling levels under careful consideration. If areas requiring intensive treatments similar to STR S3-045 are identified, STR S4-032 could be modified accordingly, subject to agency and Unified Command approval. Intensive treatments should require the continual presence of SCAT/agency advisors-monitors similar to operations under STR S3-045. It is recommended that any additional intensive treatments be delayed until 15 December 2011, and initiated and completed as rapidly as possible thereafter during the winter months, using manual crews. Following the completion of subsequent surveys and STR S4-032 operations, including any additional intensive treatments, this report should be updated.

In conclusion, it should be emphasized that the salt marsh oiling conditions encountered in Northern Barataria Bay during the *Deepwater Horizon* oil spill were substantial and persistent. The intensive manual and mechanical methods used, including vegetation raking and cutting, would not be appropriate for the majority of oil spills in salt marsh environments, and in many cases, could result in further marsh damage and limit marsh recovery. Even during this spill, only the most heavily oiled salt marshes were intensively treated—a small fraction (~1%) of the nearly 796 km (495 mi) miles of marsh shorelines that were oiled across the Gulf States. Natural recovery was the preferred and appropriate approach for the vast majority of oiled marshes.

Note: this report was written in October 2011. NOAA published it as a NOAA Tech Memo in April 2013.

1 Introduction

The *Deepwater Horizon* oil spill resulted in heavy oiling conditions in the salt marshes of Northern Barataria Bay, including portions of Bay Jimmy, Bay Batiste, Wilkinson Bay, St. Mary's Point, and vicinity (Figure 1). Due to the degree and nature of oiling in these areas, traditional marsh treatment methods, including natural attenuation, did not appear to be effective for the most heavily oiled shorelines. In addition, there was concern that long-term oiled marsh recovery could be at risk without some form of intervention. There was also the competing concern that cleanup in the marshes could cause further damage, delaying or limiting oiled marsh recovery, as has often been observed following previous oil spills. Due to these multiple factors, a series of marsh treatment field tests was conducted followed by periodic monitoring, leading to an operational-scale Shoreline Treatment Recommendation (STR). The STR was implemented to completion over a seven-month period, with various adaptive revisions. A follow-on patrol and maintenance STR was also developed and is still active as of the date of this report. The objective of this report is to document in a summary manner the marsh oiling conditions, treatment tests and monitoring, and STR treatments conducted in Northern Barataria Bay through October 2011. Following the completion of subsequent surveys, patrol and maintenance operations, and any additional treatments, this report should be updated.

2 Oiling Conditions

2.1 Oiling Events and Chronology

Initial heavy oiling in the Northern Barataria Bay marshes occurred in late May and early June 2010, with oil coming ashore primarily as mousse (emulsified oil). There continued to be oil on the water surface in the vicinity for some time. Aerial images from mid June 2010, for instance, show substantial amounts of oil on the water in Northern Barataria Bay, mostly mousse and heavy sheens but also black liquid oil in some of the protected small coves and creek mouths (Figure 2). Shoreline Cleanup Assessment Technique (SCAT) survey reports from mid June, mid July, late July, and early August 2010 indicated free oil on the water surface near these shorelines. This oil may have resulted in multiple repetitive shoreline oiling events in the area over several weeks at a minimum.

Storm surge and waves associated with Hurricane Alex in late June 2010 may have pushed oil and oiled debris deeper into some marshes in the area. Aerial observations after the storm reported oil and debris pushed several meters into the marsh in some locations. However, aerial and ground surveys in areas with heavier marsh oiling reported no obvious changes in the width of marsh oiling pre- and post-storm. Though substantial widespread changes were not documented, it is likely that the width of oiling and/or the location and size of oiled wrack lines were influenced by Hurricane Alex for at least some locations.

Hurricane Alex also resulted in large accumulations of stranded boom in these marshes and across the response area, as reported from aerial and ground observations (Figures 3 and 4). Stranded boom in the marshes included hard, sorbent, and snare boom, ranging from relatively clean to heavily oiled. Stranded sorbent boom predominated in the Northern Barataria Bay marshes. Stranded boom in the marshes was also reported regularly prior to this storm.

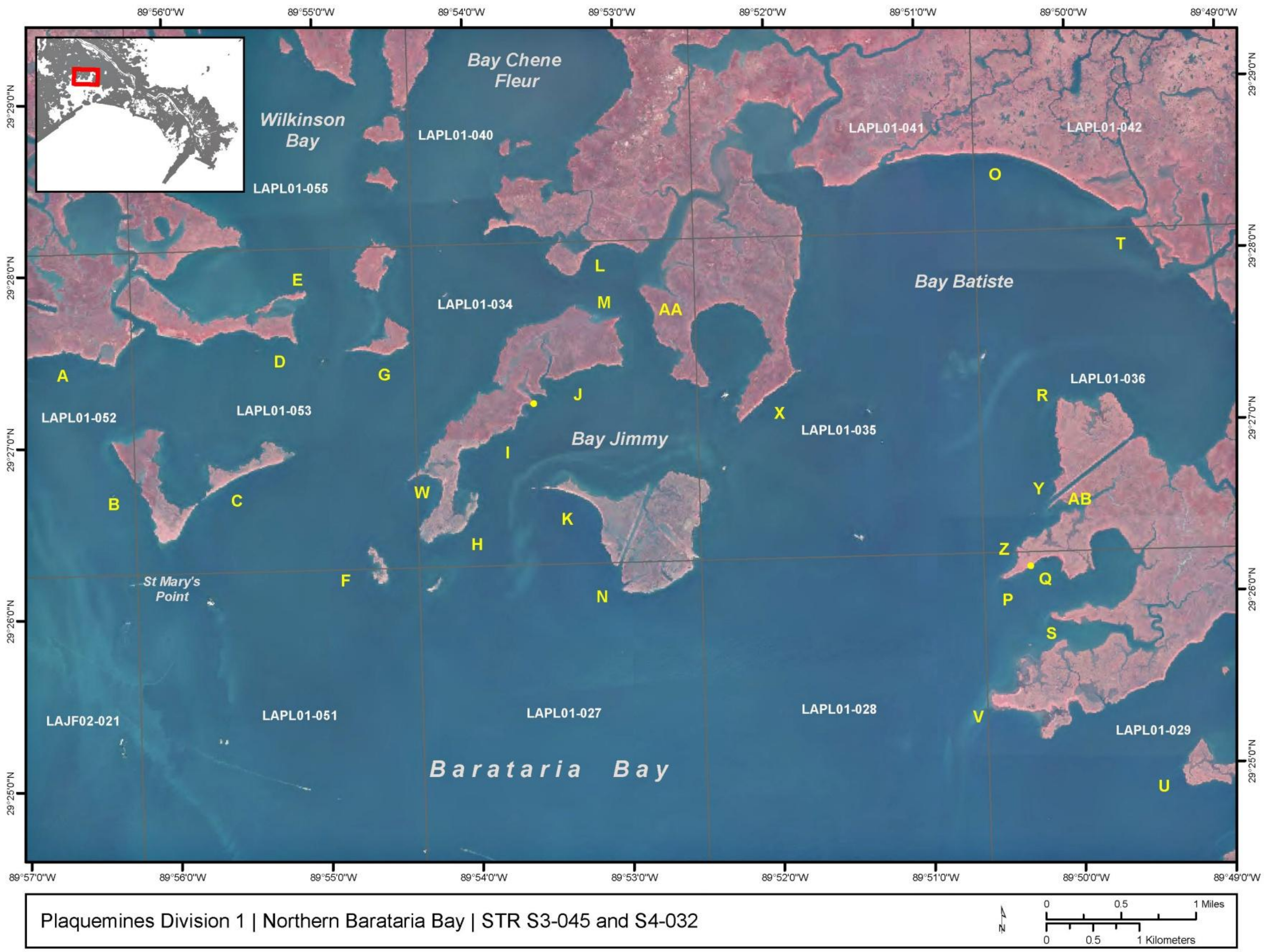

Figure 1. Location map of Northern Barataria Bay, as defined for this report. Letter annotation indicates operational shoreline "zones" referenced in subsequent figures and text.

Figure 2. Initial oiling conditions (example), aerial views, Bay Jimmy (Zone I), June 2010.

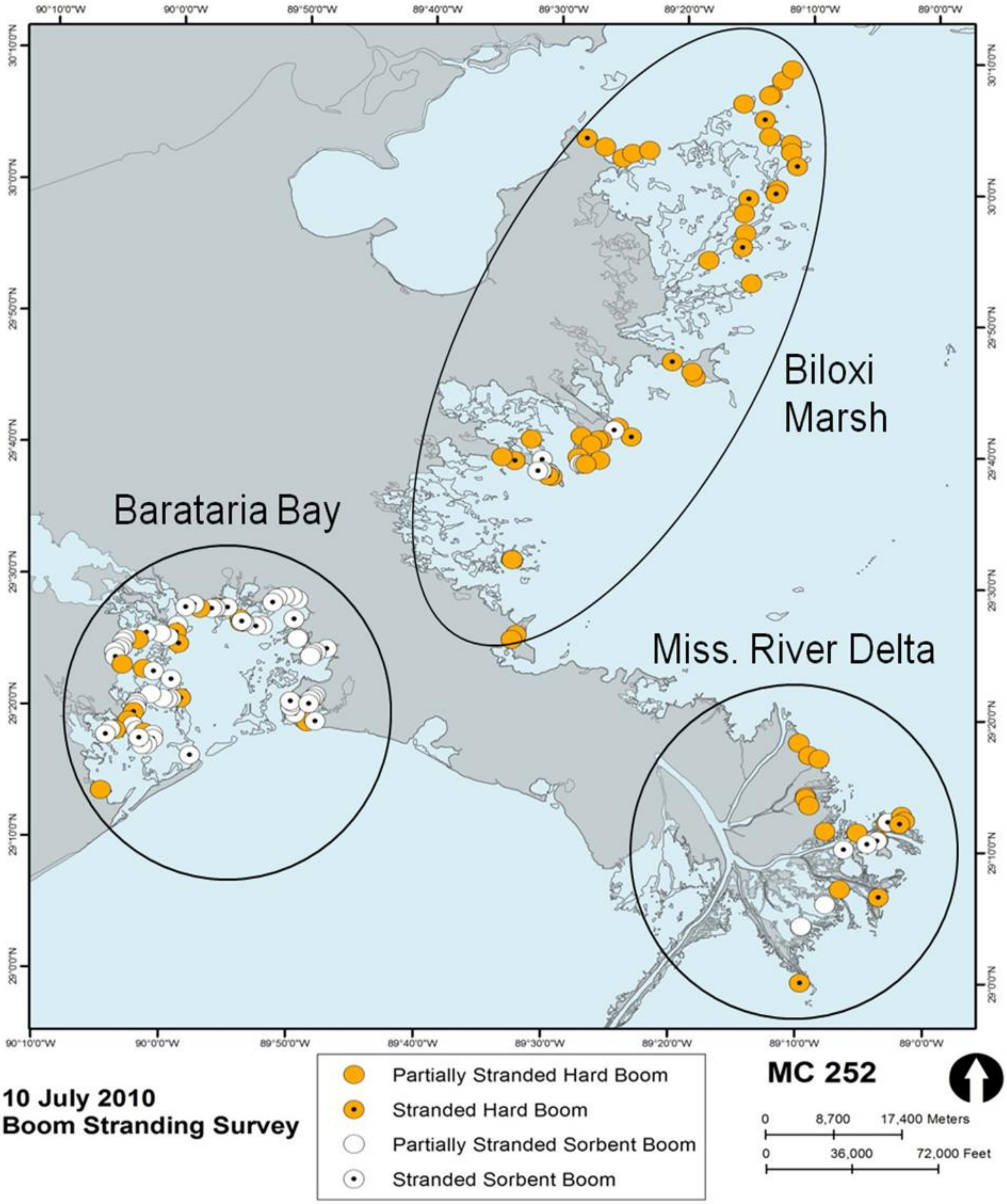

Figure 3. Stranded boom aerial survey, eastern Louisiana, including Barataria Bay, July 2010.

Figure 4. Stranded boom in the marsh. Top: stranded boom and initial oiling in Bay Jimmy (near Zone K), June 2010. Bottom: example of stranded boom scar with accumulated oil, several months following boom removal, Comfort Island, St. Bernard Parish, March 2011.

No major changes in oiling extent were reported following the passage of storms associated with Tropical Storm Bonnie in late July 2010. However, oil on the water that was possibly remobilized from the marsh by this storm was reported in one SCAT survey. Tropical Storm Bonnie also resulted in additional stranded boom in the marshes.

Source control had occurred and the reduced threat of oil on the water and repetitive oiling in the marshes was inferred in September 2010. The Macondo well was officially killed and pronounced "effectively dead" by the U.S. Coast Guard on 19 September 2010. Stage III[1] shoreline surveys began and the first Stage III STRs for Louisiana were issued in September 2010 as well.

2.2 Oiling Conditions

SCAT surveys in mid June 2010 (Stage II) documented oiling bands in the Northern Barataria marshes to several meters (m) wide with continuous distribution (91-100%), consisting predominantly of thick (>1 cm) mousse and liquid oil (Figure 5). SCAT surveys in mid July to early August 2010 reported similar conditions, with some weathering of oil coat on the marsh vegetation. Heavily oiled marsh vegetation was also reported as laid over or “flattened” in some locations in late July 2010.

In mid September 2010, a Stage III SCAT survey documented heavy oiling conditions near Bay Jimmy that had not been previously recognized. A complex oiling zone of roughly 1 kilometer (km) long and 5 m wide with 65-85% average oil distribution was noted. This zone included a thick nearly continuous heavily oiled vegetation mat with tarry coat formed by oiled vegetation that was laid over under the weight of the oil (Figure 6). A heavily oiled wrack line was also present. A layer of mousse with thickness from cover (defined as 0.1-1.0 cm thick) to pooled (> 1 cm thick) oil on the marsh sediment was trapped under the tarry oiled vegetation mat and wrack, with limited exposure to tidal flushing, sunlight, air circulation, rainfall, etc. This mousse appeared relatively “fresh” and similar to the oil that first came ashore in late May and early June, 3-4 months prior. When standing on the oiled vegetation mat, thick mousse would seep to the surface and pool around the boots of the survey team (Figure 7). Similar conditions, either in whole or part, were also noted in other locations during subsequent SCAT surveys, reconnaissance missions, and monitoring events across the Northern Barataria Bay marshes. The marsh treatment test monitoring, described below, further documented these oiling conditions in detail and over time.

2.3 Oiling Summaries

The current oiling summary for June 2010 (Figure 8) indicated widespread heavy oiling across the Northern Barataria Bay marshes, centered on Bay Jimmy. Heavy oiling spanned 36 km (22

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[1] “Stage” refers to different response plans, shoreline surveys, and cleanup operations through time: Stage I was on-water oil recovery in nearshore waters; Stage II was initial bulk oil recovery from heavily oiled shorelines until source control; Stage III was shoreline treatment according to habitat-specific guidelines following source control; Stage IV for this report addresses maintenance treatments following completion of the Stage III STR. The Shoreline Clean-up Completion Plan (SCCP) represents the final stage of the shoreline response. Sources: *Deepwater Horizon* Unified Command (DWH UC) (2010a,b; 2011a,b).

Figure 5. Initial oiling conditions, shoreline views, Bay Jimmy (Zones I and K), June 2010.

Figure 6. Persistent oiling conditions, heavily oiled wrack and vegetation mat, Bay Jimmy (Zone K), October 2010.

Figure 7. Persistent oiling conditions, pooled mousse under the vegetation mat, Bay Jimmy (Zone K), September 2010.

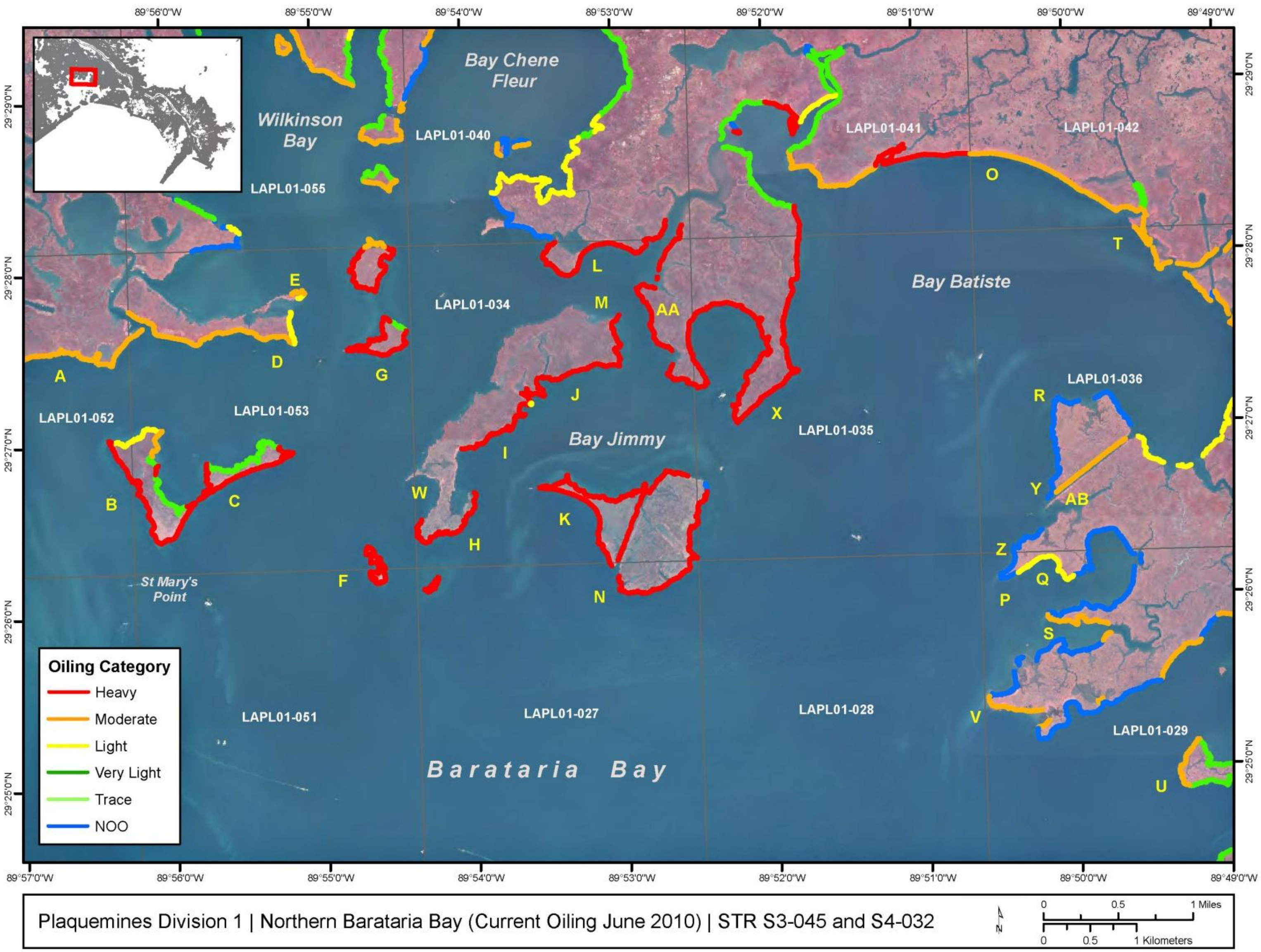


Figure 8. Current oiling summary for Northern Barataria Bay marshes, June 2010. Oiling categories based on oiling width, distribution, and thickness.

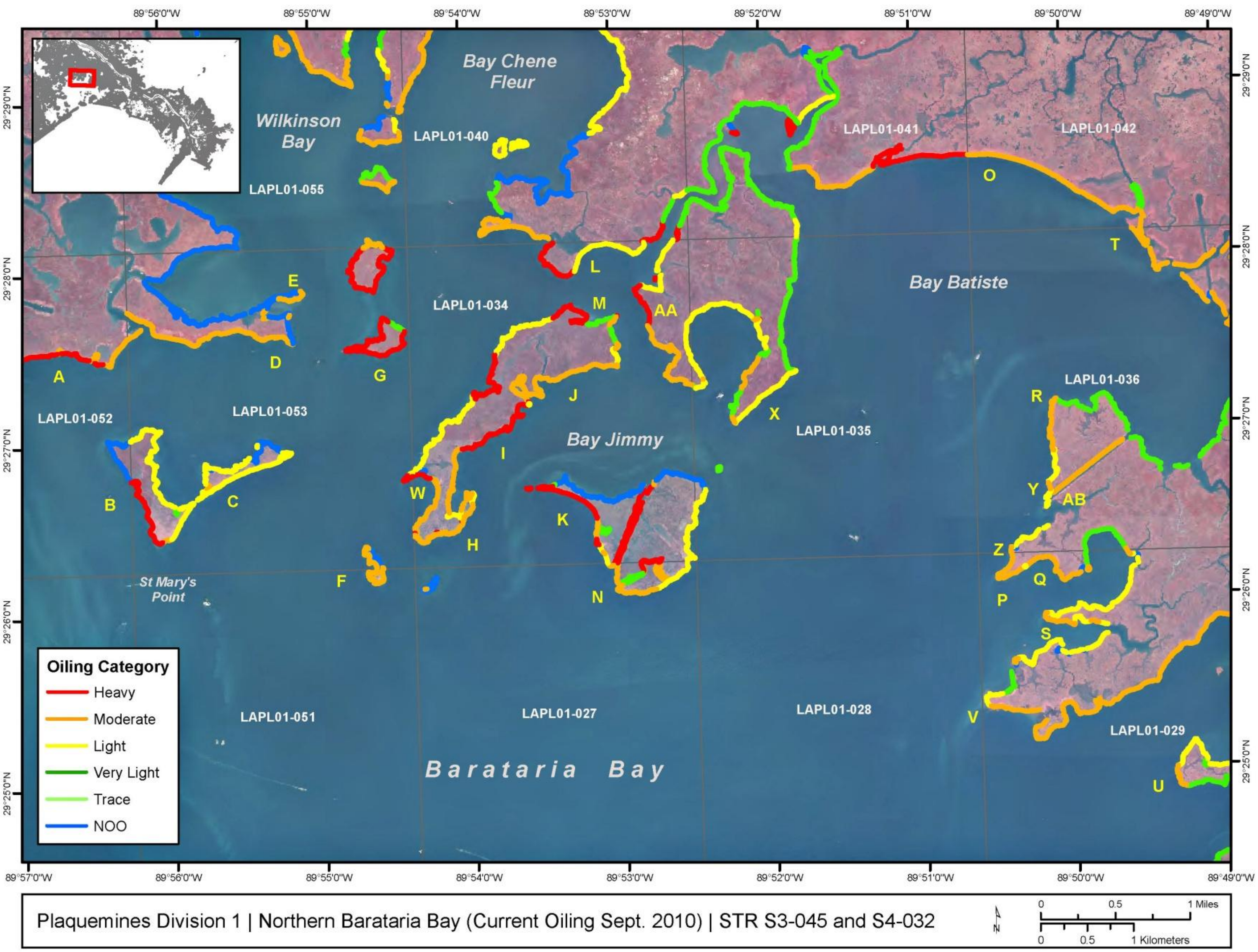


Figure 9. Current oiling summary for Northern Barataria Bay marshes, September 2010. Oiling categories based on oiling width, distribution, and thickness.

miles) and moderate oiling included 19 km (12 miles) in June 2010. The current oiling summary for September 2010 (Figure 9) showed continued heavy oiling on shorelines facing the open bay, but with many prior heavily oiled areas shifting to moderate or lesser oiling categories. Some new heavily oiled shorelines were also documented by this time, as shoreline surveys continued. Additional locations with heavy oiling were documented in continuing surveys under Stage III. Heavy oiling spanned 17 km (11 miles) and moderate oiling included 35 km (22 miles) in September 2010.

Maximum oiling conditions (showing the heaviest oiling ever observed along a segment and updated to the present; Figure 10) indicate the total maximum extent of heavy oiling across all surveys throughout the area, including nearly all of Bay Jimmy, large portions of Bay Batiste, most of St. Mary's Point, and lower portions of Wilkinson Bay. Maximum oiling statistics by category for the Northern Barataria Bay marshes are shown in Table 1. In all, 90% of marsh shorelines in this area were oiled, with 57% of shorelines heavily to moderately oiled (76 km and 48 mi combined).

Table 1. Maximum oiling for the Northern Barataria Bay marshes.

Marsh Oiling Category[1]	Shoreline Length (km)	Shoreline Length (mi)	Percent Total All (%)
Heavy	49	31	37
Moderate	27	17	20
Light	22	13	16
Very Light	19	12	14
Trace	3	2	2
No Oil Observed	13	8	10
TOTAL OILED	120	75	90
TOTAL ALL	133	83	100

[1]Calculation of marsh oiling category based on oiling width, distribution, and thickness as described in the Stage I-II Nearshore and Shoreline Response Plan (DWH UC 2010a).

3 Summary of Oiled Marsh Treatment and Recovery Literature

The oiled marsh treatment recommendations, treatment tests, and ultimate treatment operations all had a foundation on past oil spill experience and studies of prior spills in salt marsh habitats, as summarized below.

Sell *et al*. (1995) analyzed nineteen oil spill case histories and one experimental spill in salt marshes. They found that 75% of oiled salt marshes recovered within five years. In some cases, treated salt marshes recovered faster than untreated areas, whereas aggressive treatments delayed marsh recovery. Baker *et al*. (1993) studied the *Metula* spill in the Strait of Magellan (Chile, 1974) and showed that, as of

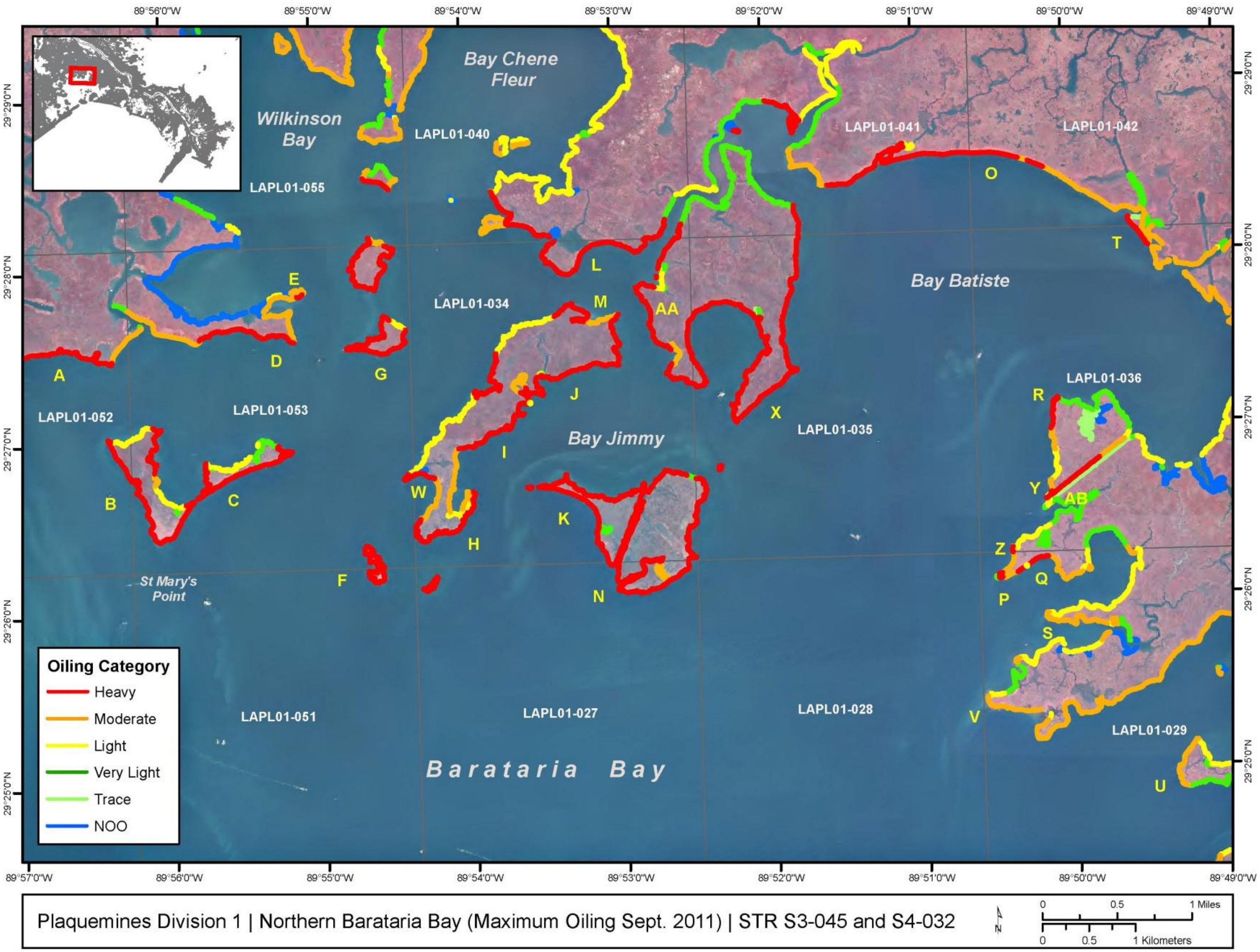


Figure 10. Maximum oiling summary for Northern Barataria Bay marshes, September 2011. Oiling categories based on oiling width, distribution, and thickness.

1993, nearly 20 years later, there was little vegetative recovery in areas with thick (mean thickness of 4 cm) layers of emulsified oil on the marsh surface.

Hoff (1995), in her report on the "fine line between help and hindrance" in responding to spills in salt marshes, summarized the recovery of seventeen spills in salt marshes (including ten in the Gulf of Mexico) and identified the factors influencing the rate of marsh recovery. The spills with the longest recovery rates were those with thick oiling, intrusive cleanup that removed the marsh soils, or heavy accumulations of a light, refined oil. She recommended the following:

> *"Cleanup in a marsh is justified when oil can be removed with minimal impact, when other resources are at high risk of being oiled (such as migrating birds), and when unassisted recovery is likely to be very slow (more than two to three years). Natural (unassisted) recovery may be the best option in cases where oiling is light and natural recovery is likely to occur in a shorter timeframe (one year or less), where cleanup activities would detrimentally impact the marsh, and where wildlife is at low risk of being oiled."*

Baker (1999) concluded:

> *"Because neither natural cleanup nor aggressive treatment provides the best environmental benefit, it seems that the greatest benefit would result from a moderate level of clean-up–sufficient to remove most of the bulk oil, but gentle enough to leave the surface of the shore intact and to avoid churning oil into underlying sediments. This can be achieved by using small crews and avoiding the use of heavy machinery as far as possible. The appearance of the shore after such treatment is likely to be somewhat oily and therefore not optimal from an aesthetic viewpoint, but there are numerous examples of biological recovery taking place in the presence of weathered oil remnants."*

Researchers at the Louisiana State University have studied several spills in Louisiana and have conducted experimental studies in greenhouses with salt marsh vegetation (e.g., DeLaune *et al*. 1979; Mendelssohn *et al*. 1990, 1993a,b; Lin and Mendelssohn 1996; Lin *et al*. 1999; Hester and Mendelssohn 2000). These studies have shown that marshes with oiling of the vegetation only recovered quickly (less than 1 year), particularly where oil only covered the stems and parts of the leaves. Oiling of marsh soils resulted in recovery rates of several years. However, the longest recoveries were for marshes with intrusive treatments that affected the soil elevation or trampled the soils.

The Louisiana Office of Coastal Protection and Restoration (OCPR 2010) also conducted a literature review and recommended caution against intrusive cleanup:

> *"Although the Incident Command should maintain a toolbox with all available response options, and evaluate under what conditions certain responses are more appropriate, OCPR recommends that in general intrusive response options be avoided, as even light foot traffic from response personnel activities can cause significant and long-lasting harm to the integrity of the soft soils underlying Louisiana's wetlands. However, it may*

be necessary to utilize these methods on a case by case basis to protect proximate wildlife and critical habitat or to remove large quantities of collected oil."

These scientific studies and literature reviews were relied upon in the decision to consider more intensive treatments for the most heavily oiled salt marshes in Northern Barataria Bay, focusing in particular on those areas with heavily oiled vegetation mats and wrack lines overlying thick mousse layers on the marsh surface and shallow subsurface.

4 Early Treatment Approaches

The Stage I and II Nearshore and Shoreline Response Plan included marsh treatment methods approved until source control was secured (DWH UC 2010a). These methods were also included in the Stage II General STRs approved per Operational Division, including Plaquemines Division 1, which covered Northern Barataria Bay. The general STRs allowed treatment of the oiled marsh fringe and associated open-water areas to recover bulk heavy oiling without site-specific surveys or STRs, as long as certain conditions and constraints were observed. Methods allowed under the general STRs included: skimming and vacuuming from boats to recover floating oil on the water surface, low-pressure flushing with ambient sea water along the marsh fringe to release bulk oil, and use of sorbent boom and snare. Under Stage II, methods such as marsh cutting, burning, and foot entry into the marsh (even on boardwalks) for manual recovery were not approved, due to concerns related to repetitive oiling and the potential damage that could be used by these treatment methods, especially if multiple treatments were required due to subsequent re-oiling.

A large number of site-specific Stage II STRs were also developed for heavily oiled marshes in Northern Barataria Bay, including Bay Jimmy, Bay Batiste, Wilkinson Bay, St. Mary's Point, and other areas. Many of these early STRs from early to mid June 2010 were not numbered. Later Stage II STRs in the area were numbered sequentially. The site-specific Stage II STRs included: targeted passive oil recovery with correctly deployed and maintained sorbent materials placed on open water near the marsh fringe; skimming and vacuum operations on open waters at the marsh edge; active combinations of booming, skimming, vacuuming, low pressure flushing, on-water herding, and use of sorbent boom (e.g., several early un-numbered STRs; STR #s 105-108, issued in mid to late June 2010); limited manual recovery of oil from the marsh fringe using nets, scoops, and sorbent materials, including potential use of walk boards on a case-by-case basis; and low-pressure flushing of oil from the marsh fringe and interior using specialized flushing barges equipped with long-reach arms (STR #s 157 and 158, issued in early August 2010). STRs for stranded boom recovery, including stranded boom in the Northern Barataria Bay marshes, were also developed and issued in mid July and early August 2010 (STR #s 126 and 126-revised). These STRs prescribed the earliest widespread use of walk boards to allow small manual crews to access marsh areas, and resulted in the removal of large amounts of stranded.

Operations-based demonstrations with low-pressure marsh flushing equipment under STR #158 were conducted in Northern Barataria Bay on two occasions, using two different sets of equipment. One set of equipment was ineffective due to insufficient water volume delivery. Demonstrations were conducted over two days in mid September 2010 with low-pressure, high-volume flushing equipment immediately following the Stage III SCAT survey described above. This equipment included a long-reach hydraulic arm, a wide flushing head with nozzles, and articulated controls allowing changes in flushing height, direction, and angle, including the ability to conduct sweeping or “combing” motions with the flushing spray (Figure 11). Though this equipment seemed very promising, and had been used in oiled marshes elsewhere (St. Bernard Parish), the marsh flushing demonstration was not effective in mobilizing the pooled oil trapped under the oiled vegetation mat, even at flushing pressures and durations that exceeded the specifications in the STR. Little-to-no-oil was mobilized during the demonstrations, due at least in part to deflection and baffling by the overlying oiled vegetation mat and the possible weathering state of the mousse below. Potential damage to the marsh platform was observed during the demonstration, including scouring of marsh sediments.

An early Stage III STR was written to guide pre-existing and on-going vessel-based marsh vacuum operations (Figure 12) that were attempting to remove pooled oil directly from the marsh substrate in Northern Barataria Bay (STR S3-008, issued in mid September 2010). This included pre-STR operations observed during the SCAT survey described above in mid September. The STR provided guidelines for avoiding and minimizing marsh damage during marsh vacuum operations. These operations were controversial, with differing reports on the effectiveness and effects of this method. Large volumes of recovered oil were reported in some cases, but other reports disputed this and also reported potential marsh damage, including the removal of marsh sediments and gouging of the marsh substrate. This STR was ultimately rescinded based on SCAT and Environmental Unit field observations, including the results of the marsh treatment tests described below.

Ultimately, operations under the Stage II and III STRs described above (other than STR #126 for stranded boom) were not effective in treating the heavy marsh oiling conditions documented in mid September 2010 for Northern Barataria Bay, and in some cases were considered potentially damaging to the marsh.

5 Marsh Treatment Tests

5.1 Test Needs and Planning

Considering the information presented above, the SCAT Program suggested field tests of various treatment options to address the heavy marsh oiling conditions in Northern Barataria Bay. A meeting of the *Deepwater Horizon* Marsh Technical Working Group (TWG) was called in mid September 2010 to discuss the topic, including an initial proposal from the SCAT Program for treatment testing. Multiple federal, state, and BP representatives from the Marsh TWG, Louisiana (Houma) Core Group, SCAT, the Alternative Response Technology Evaluation System (ARTES) Program, and the Resources-at-Risk Program were in attendance. All parties agreed that testing should go forward immediately, based on the degree and extent of heavy marsh oiling, the concern that long-term oiled marsh recovery could be limited or delayed without treatment, the ineffectiveness of prior methods, the need to develop more effective treatments options, and the potential for further damage to the marsh posed by more aggressive treatments. Meeting participants concurred that the proposed testing had the approval of the Marsh TWG and Louisiana Core Group, and the tests were scheduled for late September 2010, pending Regional Response Team (RRT) approval.

Figure 11. Marsh flushing demonstration in Bay Jimmy, September 2010.

Figure 12. Vessel-based marsh vacuum operations, September 2010.

A RRT Region VI application for the treatment testing, including a detailed study plan, was developed and submitted by the SCAT Program and Marsh TWG three days after the Marsh TWG meeting. RRT approval was required because two surface washing agents and *in-situ* marsh burning were being considered as potential treatments. An RRT meeting was convened two days later, and all members other than the State of Louisiana (represented by LOSCO) concurred that the tests should proceed as proposed. The State of Louisiana requested additional time to consult among the various state agencies, and followed with an email shortly thereafter stating non-concurrence pending further state review and additional plan involvement. The original test dates were postponed and a meeting and field visit with personnel from multiple state agencies was arranged, resulting in a revised study plan. This plan was circulated to the Marsh TWG and RRT in early October and approved two days later. Landowner and parish approvals for the tests were also obtained.

5.2 Test Design

The treatment methods in the revised plan were:

- Vegetation cutting
- Vegetation cutting followed by low pressure flushing
- Vegetation cutting followed by PES-51 application and flushing
- Vegetation cutting followed by Cytosol application and flushing
- Vegetation cutting followed by marsh vacuum treatments
- Natural recovery (no treatment).

These methods and combination of methods were proposed to first address the removal or reduction of the overlying heavily oiled vegetation mats, allowing improved natural tidal flushing, weathering, and degradation of the thick mousse on the marsh substrate, and allowing greater access to and treatment of the thick oil on the substrate. The secondary treatments were proposed to remove or reduce the underlying mousse layer once it was exposed by cutting. Natural recovery was proposed for comparison, including evaluation of potential marsh damage by the other methods and vegetation recovery.

Vegetation cutting was to be conducted with weed trimmers, including metal brush cutting attachments if needed. Low-pressure flushing was to be conducted by the specialized long-reach marsh-flushing barge used in the prior demonstrations, but modified to better control water pressure and duration of flushing, according to the specifications in STR #158. Both PES-51 and Cytosol are "lift and float" surface washing agents listed on the Product Schedule of the National Contingency Plan (NCP), rather than dispersants. Surface washing agents were proposed to loosen the oil from the substrate to improve the effectiveness of flushing. Both agents were tested in tailgate trials on heavily oiled marsh vegetation collected from Bay Jimmy, with moderate but encouraging results. The marsh vacuum treatment was to use the equipment already in operation, following the specifications in STR S3-008.

In-situ marsh burning was considered as another method to remove or reduce the overlying oiled vegetation mats and perhaps remove some of the mousse below. However, this treatment method was eliminated from the treatment tests for several reasons. First, tailgate tests conducted on heavily oiled vegetation from Bay Jimmy showed that ignition of the vegetation was difficult and that it did not maintain a flame when the ignition source was removed. In addition, because the vegetation was so "flattened" to the substrate and wetted, it was thought that these marshes lacked standing fuel and adequate air circulation to successfully "carry a flame" like a typical marsh burn. Most importantly, marsh burns during oil spills are typically conducted during high tides with a layer of water over the marsh substrate, to protect the marsh soils and plant rhizomes from flames and heat. Under the oiling conditions in question, the oiled vegetation and substrate were below the water surface during high tides, and not accessible for burning. It was thought that the emulsified state of the oil (high water content) would reduce burn effectiveness and potentially worsen the oiling conditions and further limit the effectiveness of other treatments. Finally, some agencies raised safety and environmental concerns regarding burning.

The test design leading into the treatment tests in early October 2010 included three randomly assigned replicates of each of the six treatments listed above, for a total of eighteen test plots. The test site corresponded to a portion of the same shoreline documented in the mid September 2010 SCAT survey that described the oiling conditions being targeted (Figure 13). Test plot size was 6 m (20 feet [ft]) along shore and roughly 9-10 m (~30 ft) wide, corresponding to the landward limit of the heavily oiled wrack line. Testing parameters included plot-specific detailed SCAT assessments (surface and subsurface oiling condition), vegetation cover, species composition, and surface oil and sediment chemistry. Time-series photography was also collected.

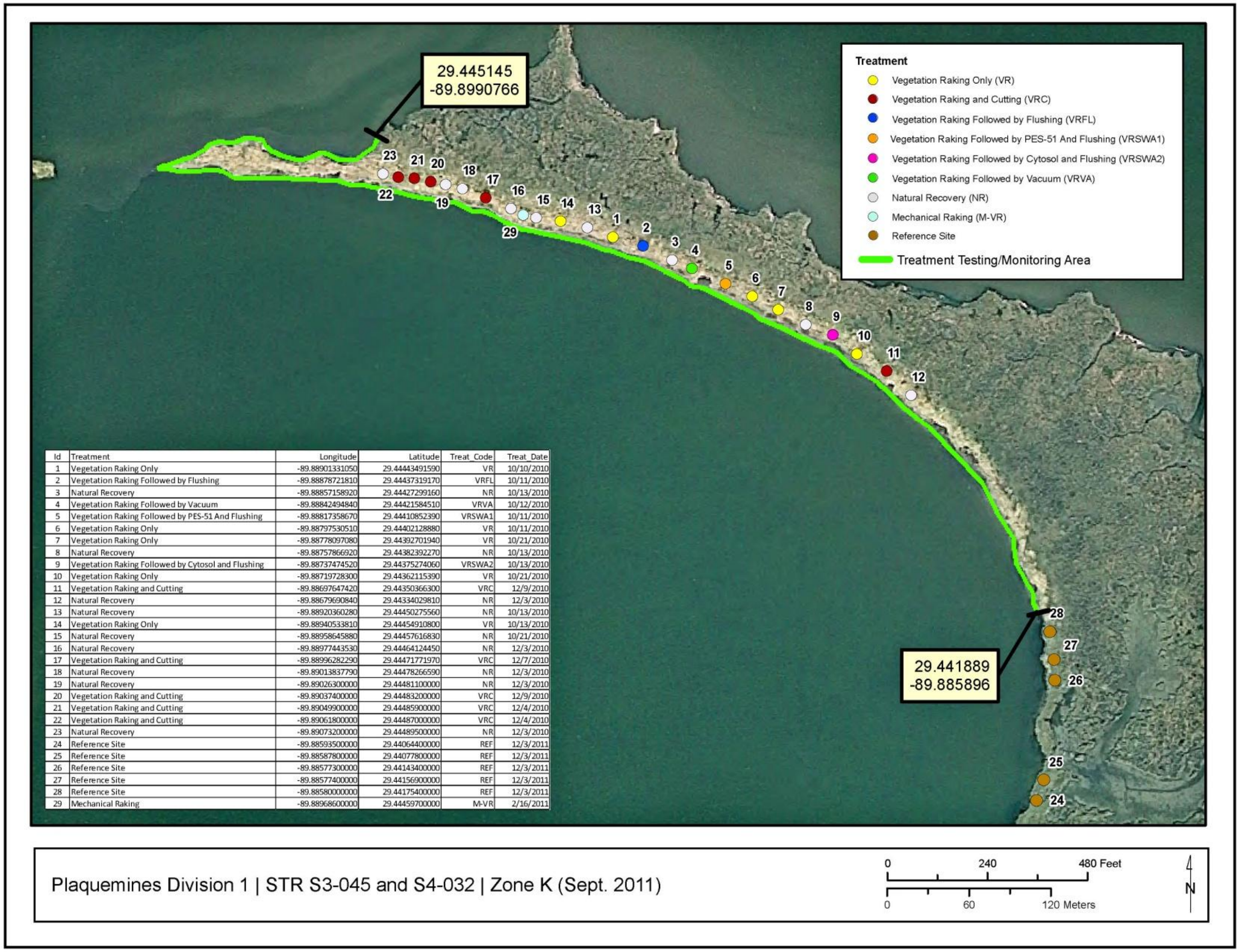
5.3 Test Implementation and Initial Results – October 2010

Prior to the tests, the plots were marked in the field (Figure 14), and pre-treatment SCAT assessments were performed, including participation by federal, state, BP, and parish representatives. Each plot was also bounded with sorbent boom. Hard boom was placed on the water side of the plots that were scheduled for the flushing and surface washing agent treatments.

Pre-treatment oiling conditions were very similar across all plots. Based on multiple assessments, including at least three shovel test pits per plot to measure oil thickness and determine presence and distribution of oil on the sediment beneath the oiled vegetation mats and wrack, two distinctive oiling zones were described for each plot.

"Oiling Zone A" was a 1-3 m (3-10 ft) wide band on the lower marsh edge consisting of exposed surface oil residue with typically broken (51-90%) to continuous (91-100%) distribution and cover (≤1 cm) thickness (Figure 15). The thin top layer of this surface oil residue had a dry, hard, crusty to tarry consistency, and included the presence of thin algal mats and surface cracking. The aboveground vegetation in this zone had sloughed off leaving only short stubble. During the treatment tests, this oiling zone was not treated, because the oil appeared to be relatively weathered and due to concern that treatment could destabilize the seaward marsh edge and potentially lead to increased erosion.

"Oiling Zone B" was a 5-10 m (20-30 ft) wide band on the marsh platform extending from Oiling Zone A to the inland extent of oiling. Zone B included oil on both the vegetation and sediments. The vegetation oiling consisted of dead, laid over, rooted marsh vegetation forming heavily oiled vegetation mats



Id	Treatment	Longitude	Latitude	Treat_Code	Treat_Date
1	Vegetation Raking Only	-89.88901331050	29.44443491590	VR	10/10/2010
2	Vegetation Raking Followed by Flushing	-89.88878721810	29.44437319170	VRFL	10/11/2010
3	Natural Recovery	-89.88857158920	29.44427299160	NR	10/13/2010
4	Vegetation Raking Followed by Vacuum	-89.88842494840	29.44421584510	VRVA	10/12/2010
5	Vegetation Raking Followed by PES-51 And Flushing	-89.88817358670	29.44410852390	VRSWA1	10/11/2010
6	Vegetation Raking Only	-89.88797530510	29.44402128880	VR	10/11/2010
7	Vegetation Raking Only	-89.88778097080	29.44392701940	VR	10/21/2010
8	Natural Recovery	-89.88757866920	29.44382392270	NR	10/13/2010
9	Vegetation Raking Followed by Cytosol and Flushing	-89.88737474520	29.44375274060	VRSWA2	10/13/2010
10	Vegetation Raking Only	-89.88719728300	29.44362115390	VR	10/21/2010
11	Vegetation Raking and Cutting	-89.88697647420	29.44350366300	VRC	12/9/2010
12	Natural Recovery	-89.88679690840	29.44334029810	NR	12/3/2010
13	Natural Recovery	-89.88920360280	29.44450275560	NR	10/13/2010
14	Vegetation Raking Only	-89.88940533810	29.44454910800	VR	10/13/2010
15	Natural Recovery	-89.88958645880	29.44457616830	NR	10/21/2010
16	Natural Recovery	-89.88977443530	29.44464124450	NR	12/3/2010
17	Vegetation Raking and Cutting	-89.88996282290	29.44471771970	VRC	12/7/2010
18	Natural Recovery	-89.89013837790	29.44478266590	NR	12/3/2010
19	Natural Recovery	-89.89026300000	29.44481100000	NR	12/3/2010
20	Vegetation Raking and Cutting	-89.89037400000	29.44483200000	VRC	12/9/2010
21	Vegetation Raking and Cutting	-89.89049900000	29.44485900000	VRC	12/4/2010
22	Vegetation Raking and Cutting	-89.89061800000	29.44487000000	VRC	12/4/2010
23	Natural Recovery	-89.89073200000	29.44489500000	NR	12/3/2010
24	Reference Site	-89.88593500000	29.44064400000	REF	12/3/2011
25	Reference Site	-89.88587800000	29.44077800000	REF	12/3/2011
26	Reference Site	-89.88577300000	29.44143400000	REF	12/3/2011
27	Reference Site	-89.88577400000	29.44156900000	REF	12/3/2011
28	Reference Site	-89.88580000000	29.44175400000	REF	12/3/2011
29	Mechanical Raking	-89.88968600000	29.44459700000	M-VR	2/16/2011

Figure 13. Marsh treatment test plots. Plots 1-10, 12-16, 18-19, and 23 correspond to the October 2010 treatment tests and final natural recovery (no treatment) plots. Plots 11-12 and 16-23 correspond to the December 2010 treatment tests and associated natural recovery plots. Plots 24-28 are reference plots. Plot 29 was a mechanical demonstration plot, February 2011.

Figure 14. Marsh treatment test plots, aerial and ground views.

Figure 15. Oiling Zone A, lower marsh edge, surface oil residue with cover thickness, this zone was typically not treated.

with a continuous oil coat (<0.1 cm thickness) of tarry consistency along the entire length of the plant stems, as well as heavily oiled wrack deposited at the high-water line (Figure 16). The sediment oiling consisted of continuous thick mousse (>1 cm) trapped under the oiled vegetation mats and wrack (Figure 17). Much of this mousse was 2-3 cm thick across the marsh platform and typically heaviest near the oiled wrack, to 5-8 cm thick. Subsurface oiling conditions were also observed, including burial of oiled vegetation mats or the underlying mousse layer by fine sediments or organic detritus. A few instances of oiled crab burrows or oiled shoot/root channels were also observed. Oiling conditions in Zone B were the focus of the treatment testing and monitoring and are emphasized below and in subsequent sections.

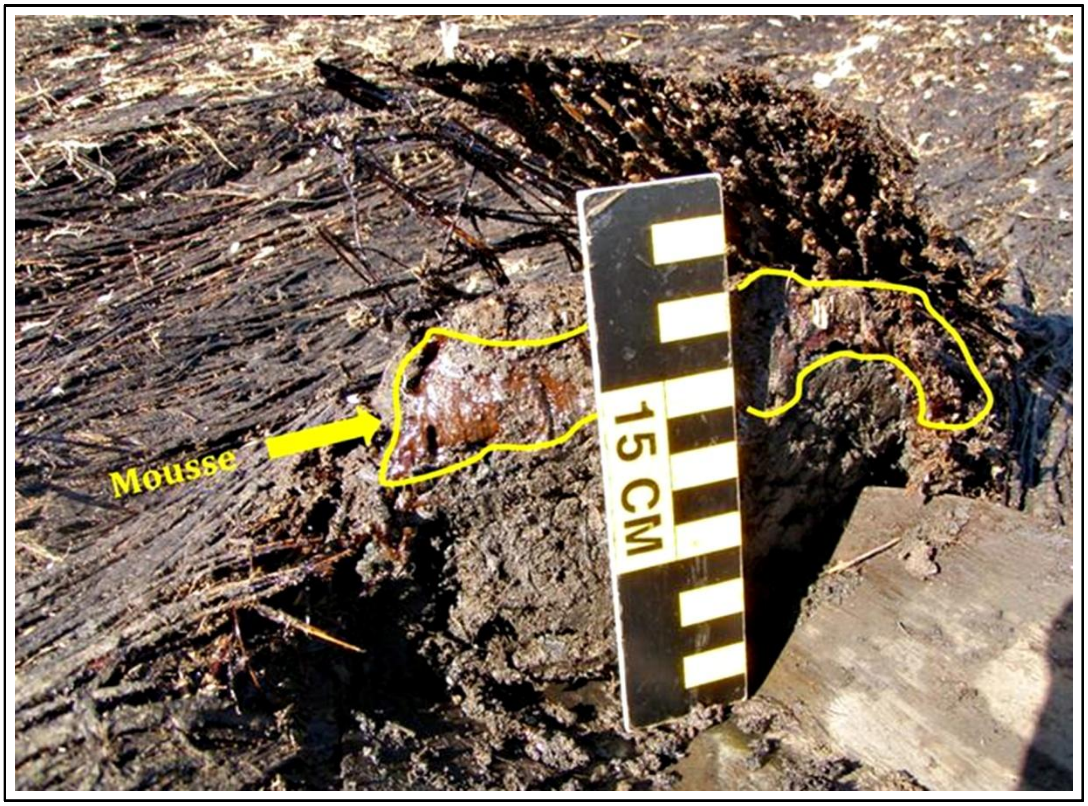
Initial test implementation was conducted over early to mid October 2010. Federal, state, and BP representatives from SCAT, the Environmental Unit, Operations, Safety, and other programs and units participated in and/or observed the tests. Parish representatives also participated in the field tests.

At the onset, it was apparent that cutting the oiled vegetation mat with weed trimmers was not effective, even when using different cutting attachments and raking the mat prior to cutting. This was due to the thickness of the mats, their flattened nature, and the density of the tarry coat on the vegetation. However, the raking treatment did appear effective at breaking up the mat and exposing the thick mousse below (Figure 18). It was also felt that raking would have some advantages over cutting, in terms of potential damage to the marsh. Raking was therefore substituted for the proposed cutting treatments.

Raking was conducted with garden rakes by manual teams using walk boards (Figure 19). There was no direct foot access to the marsh during operations. Raking was not conducted on the lower (seaward) section of the marsh platform (Zone A), where oiled vegetation mats were not present, and surface oiling was mainly weathered surface residue. Raking was conducted across the wider middle and upper marsh platform, corresponding to the heavily oiled vegetation mats and wrack lines with underlying mousse (Zone B). Raking was conducted so that loose oiled vegetation debris was removed for disposal and plant stems that remained rooted were stood up in place. Care was taken to avoid and minimize uprooting the vegetation. Raking was conducted to the depth of the top of the mousse layer. Raking into the mousse layer was minimized to avoid mixing oil into the sediments. The secondary treatments, including low-pressure flushing, surface washing agents followed by flushing, and marsh vacuum were applied as soon a possible following raking.

Low-pressure flushing following raking mobilized abundant silver sheen to the water surface, covering roughly 80% of the on-water boomed area (Figure 20). More sheen was observed than in prior demonstrations without raking, indicating that the raking had the desired effect of exposing the mousse to treatment and natural flushing and weathering processes; however, the thick mousse layer remained in place. Some scouring of marsh sediments was also observed. Because this secondary treatment method seemed to offer limited gain in treatment effectiveness, low-pressure flushing was not replicated as a treatment.

Figure 16. Oiling Zone B, heavily oiled vegetation mats and wrack.



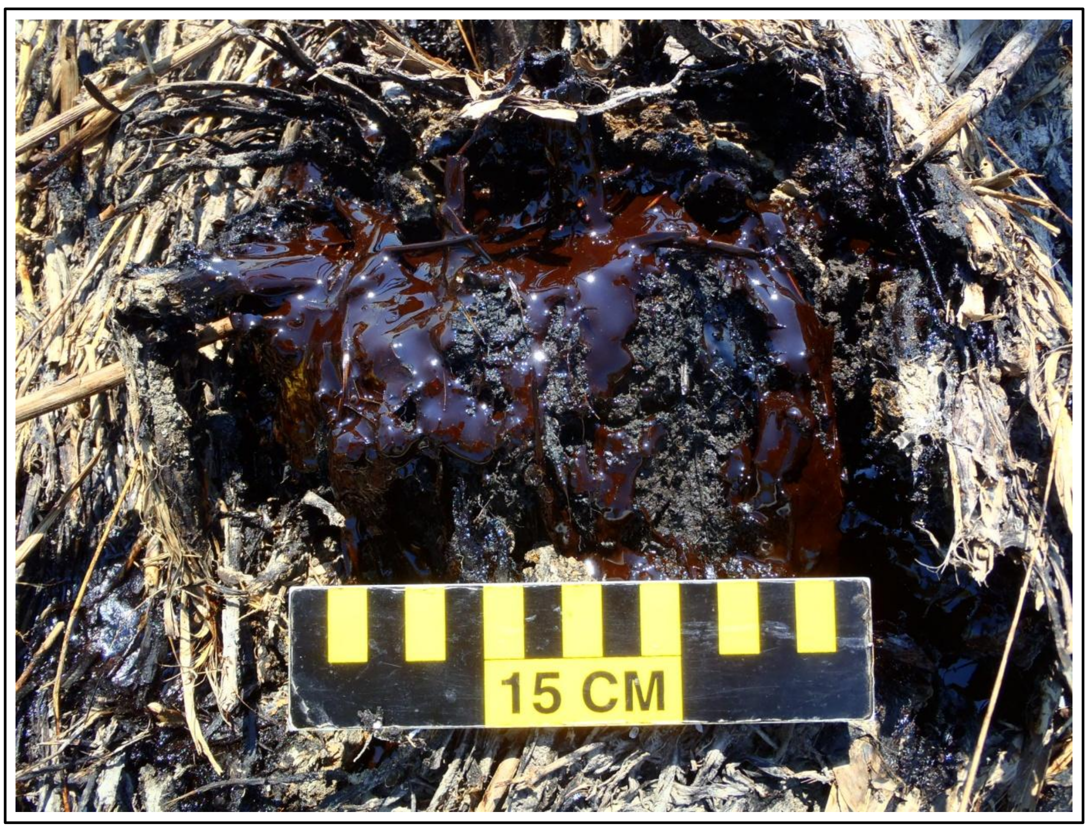


Figure 17. Oiling Zone B, thick mousse trapped under the oiled vegetation mats and wrack.

Figure 18. Oiling Zone B, post-raking condition, October 2010.

Figure 19. Raking from the walk boards, October 2010.

Figure 20. Marsh flushing following raking, October 2010.

The surface washing agent applications following raking, including PES-51 and Cytosol applied in two different plots, combined with flushing, mobilized a minor amount of liquid oil and mousse to the water surface (Figure 21). The PES-51 application seemed to mobilize a greater amount of oil than the Cytosol, in the form of liquid oil rather than mousse; however, the oil appeared to naturally disperse once it was on the water surface. The Cytosol mobilized what appeared to be mousse mixed with fine organic debris off the marsh. In both cases, the amount of oil released was much less than the amount of oil remaining on the marsh. Scouring of marsh sediments was also observed due to the flushing treatments. Because the surface washing treatments seemed to offer limited gain in treatment effectiveness, they were not replicated further.

The marsh vacuum treatment following raking (Figure 22) included two different vacuum systems that were in use under the existing STR S3-008. One of these systems included a low-pressure, low-volume water spray applied just prior to vacuuming. The vacuum application was modified in the field to allow the vacuum operators to access the marsh directly on walk boards to allow them to be closer to the marsh and mousse layer, and better able to see and apply the method (as compared to operating from the vessels). Observations during the tests indicated that very little oil was removed by vacuum; most of the material collected was water and sediment. Following treatment, the amount of mousse remaining on the substrate was little changed compared to pre-treatment conditions. The vacuum treatments also gouged the marsh sediments, creating holes that allowed the mousse to slowly seep deeper into the sediments. Because the vacuum treatment seemed ineffective and potential damaging, it was not replicated further. The results of the treatment tests, coupled with other observations, led to STR S3-008 being cancelled, halting all marsh vacuum operations (documented as STR S3-008.r.1).

Based on these initial results, only the vegetation raking alone was considered a potentially viable treatment method. All parties agreed that the other treatments should not be considered further. There were differing views on whether or not raking should be expanded operationally. Some parties felt that the method showed promise and should have been scaled-up to an STR and operational treatments immediately following the tests. Other parties felt that the method was too aggressive and could result in further marsh damage. In a meeting attended by SCAT and state agency representatives from the Marsh TWG, the majority indicated that monitoring should be conducted over the next 1-2 months, including comparisons between the raking and natural recovery plots followed by re-evaluation of whether or not raking should be applied on a larger scale. In addition, because there were still several established but un-used plots, the remaining plots were assigned to additional vegetation raking and natural recovery treatments over the next several days.

At the end of the initial treatment tests in mid October 2010, the following treatments and replicates had been established:

- Vegetation raking only – 5 plots
- Vegetation raking and low pressure flushing – 1 plot
- Vegetation raking, PES-51 application, flushing – 1 plot
- Vegetation raking, Cytosol application, flushing – 1 plot

Figure 21. Surface washing agent and flushing following raking, October 2010.

Figure 22. Marsh vacuuming from walk boards following raking, October 2010.

- Vegetation raking and marsh vacuum treatment – 1 plot
- Natural recovery (no treatment) – 9 plots
- Number of plots with raking as primary treatment – 9 plots
- Total number of plots – 18 plots.

Initial post-treatment monitoring results in November 2010 indicated no difference in oiling conditions between the treated and natural recovery plots, and no changes in oiling conditions pre- and post-treatment. The remaining rooted vegetation across most of each treated plot had lain back down on top of the mousse layer, and the oiled vegetation mats had re-formed over the oil on the substrate, which remained trapped with limited exposure to natural removal processes (Figure 23). Therefore, the vegetation raking treatments alone were considered ineffective at exposing the mousse layer and potentially enhancing natural flushing, weathering, and degradation. Monitoring results are discussed in further detail below.

5.4 Additional Test Design and Implementation – November-December 2010

After the initial monitoring results for the October tests were reviewed, an immediate search began for other options, with a focus on identifying a different cutting tool that could be used following raking. Three days following the monitoring, a demonstration-scale test of various raking and cutting tools was conducted on the marsh. During the demonstration, the combination of raking and the use of an articulating power hedge-trimmer “on a pole” was identified as a promising method. Like before, cutting alone was not feasible or effective due to the oiling and marsh conditions.

At this point, additional testing was proposed and planned using the new combined vegetation raking and cutting method, following the outline of the prior study design. RRT, state, parish, and landowner approvals were obtained for the tests. Five additional test plots were planned. The five new plots and the nine prior natural recovery plots were pooled and five replicate raking and cutting treatment plot locations were randomly assigned from the pool of 14 plots. The remaining nine plots were retained as natural recovery plots. Five reference plots in an adjacent area with very light to no current oiling, intact marsh vegetation, and similar physical setting were also selected for future vegetation comparisons.

The new plots were established, boom was deployed, and pre-treatment assessments were conducted over late November to early December. The additional treatment tests were conducted in early December 2010. As before, federal, state, BP, and parish representatives from SCAT, Operations, and other programs participated in the pre-treatment set-up and test treatments. As before, raking was not conducted on the lower (seaward) section of the marsh platform, where oiled vegetation mats were not present, and surface oiling was mainly weathered surface residue. The raking component of the treatment was field modified to include more aggressive raking. Rather than raking to the top of the underlying mousse layer, workers raked down through the mousse, stopping when clean sediments were encountered. During raking, the mousse was “spread” up onto the standing vegetation prior to cutting and removal, in order to remove additional mousse and reduce the degree of surface oiling.

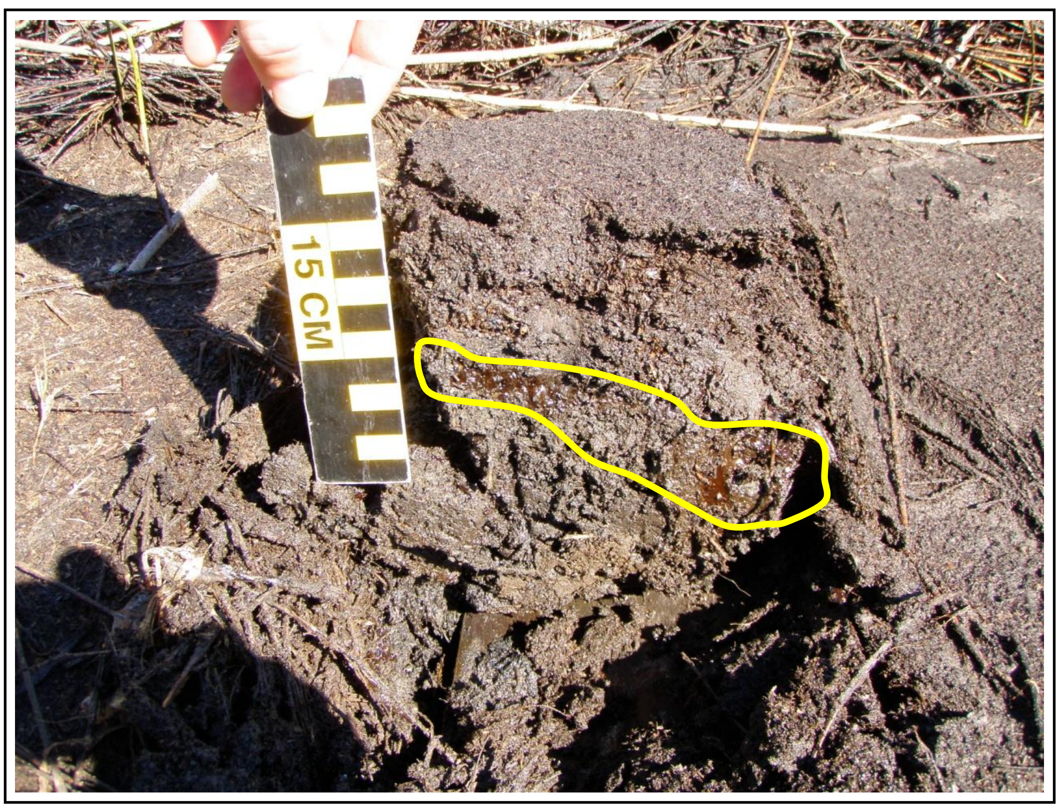


Figure 23. Re-established oiled vegetation mat following raking, thick mousse remains trapped beneath the mat ("coffee grounds" deposited on top of mat in bottom photograph), November 2010.

The overall treatment sequence included oiled wrack removal (including cutting the tarry wrack into sections for removal, where needed), aggressive raking of the oiled vegetation mat, cutting the raked vegetation with the hedge trimmer (Figure 24), additional raking and cutting where needed, and light raking as the workers backed their way out of the plots. All work was conducted on walk boards. A short standing stubble of vegetation remained following treatment (Figure 25).

At the end of the additional treatment tests in early December 2010, the following treatments and replicates were in place:

- Vegetation raking only – 5 plots
- Vegetation raking and low pressure flushing – 1 plot
- Vegetation raking, PES-51 application, flushing – 1 plot
- Vegetation raking, Cytosol application, flushing – 1 plot
- Vegetation raking and marsh vacuum treatment – 1 plot
- Number of plots with raking as primary treatment (Oct 2010) – 9 plots
- Vegetation raking and cutting (with more intensive raking, Dec 2010) – 5 plots (new)
- Natural recovery (no treatment) – 9 plots (5 associated with the Dec 2010 tests)
- Reference sites – 5 plots (new)
- New total number of plots = 28 plots.

During the pre-treatment plot assessments, no differences were observed between the planned vegetation raking and cutting plots and the natural recovery plots. Oiling conditions were very similar to what had originally been observed during the mid September 2010 SCAT survey and the earlier treatment plot assessments.

Initial monitoring results in early January 2011 (one month after the treatments) indicated the complete and persistent removal of the heavily oiled vegetation mats and wrack in the raked and cut plots (Table 2). What had been the underlying oil layer had changed from a predominance of mousse to a predominance of surface residue across all five of the vegetation raking and cutting plots (Figure 26). Federal, state, and parish representatives concurred with this observation, as did BP representatives on a subsequent site visit. Mousse was still present in many cases, but its thickness was reduced. In some areas, no mousse was observed where it had previously been present. Some of the surface residue was also observed to be breaking up on the marsh surface, and there were patchy areas lacking surface oil. There were no observed signs of increased oil penetration or mixing of oil into the sediments in the treatment areas. There were also no obvious indications of accelerated erosion in treatment areas, relative to adjacent oiled, untreated areas. The natural recovery plots remained unchanged (Figure 27).

Based on the early results of the vegetation raking and cutting tests, a decision was made in coordination with the Unified Command to draft a wider-scale STR for circulation to the various environmental and natural resource agencies for review (Section 6).

Figure 24. Cutting the oiled vegetation mat with the power hedge trimmer, following intensive raking, December 2010; detail of cutting tool.

Figure 25. Marsh conditions immediately after raking and cutting, oiled vegetation mats and wrack completely removed, December 2010.

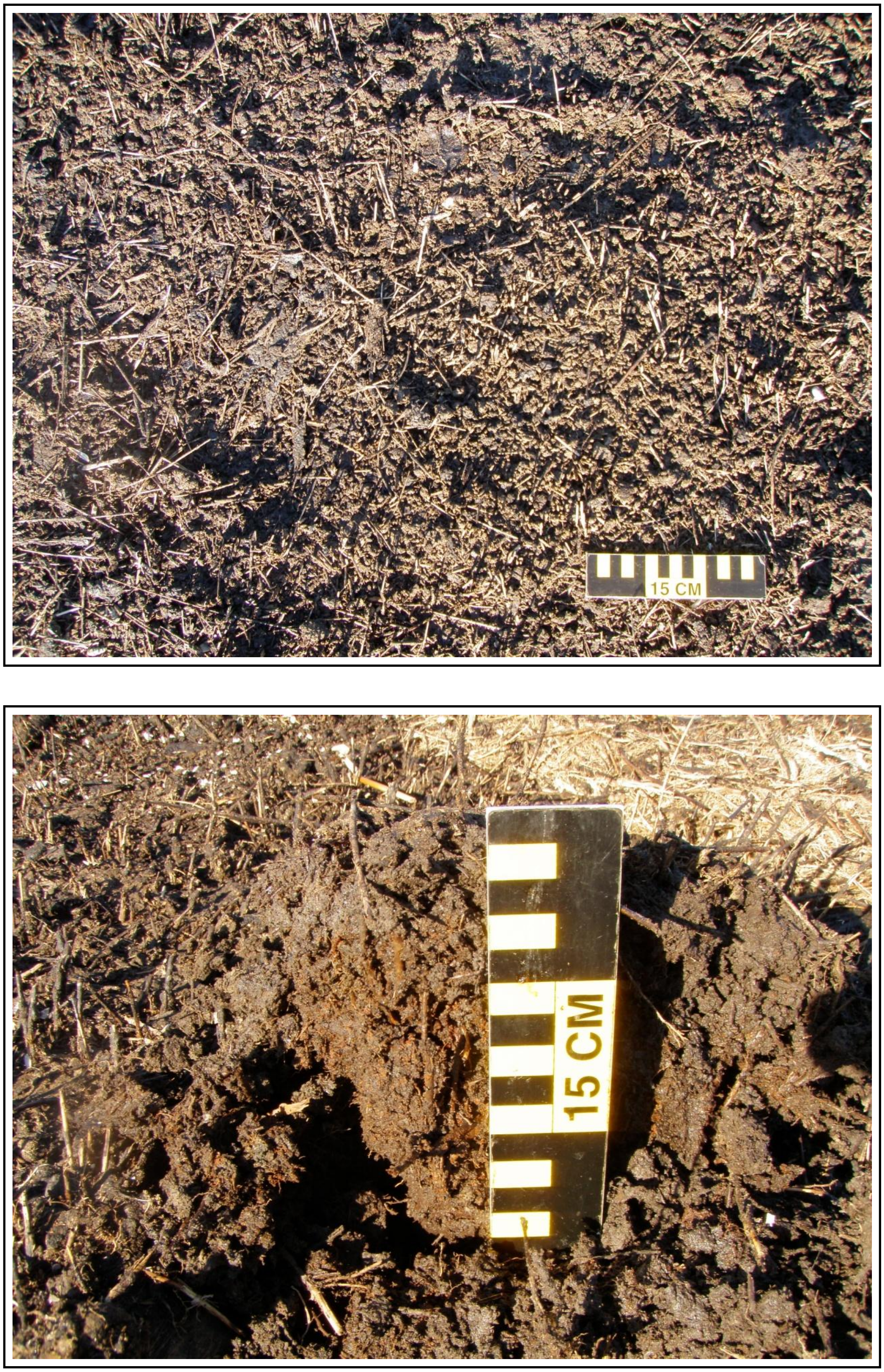


Figure 26. Marsh conditions one month following raking and cutting, plant stubble with surface residue, shovel pit lacking mousse, January 2011.

Figure 27. Marsh conditions with natural recovery (no treatment), oiled vegetation mats and thick mousse remain, January 2011.

Table 2. Short-term summary oiling conditions for the December 2010 Treatments[1].

Treatment Plots	Pre-Treatment	Post-Treatment (1-month)
Vegetation Raking and Cutting		
11	OW, OVM, TO/MS	TO/SR
17	OW, OVM, TO/MS	TO/SR
20	OW, OVM, TO/MS	TO/SR
21	OW, OVM, TO/MS	TO/SR
22	OW, OVM, TO/MS	TO/SR
Natural Recovery (No Treatment)		
12	OW, OVM, TO/MS	OW, OVM, TO/MS
16	OW, OVM, TO/MS	OW, OVM, TO/MS
18	OW, OVM, TO/MS	OW, OVM, TO/MS
19	OW, OVM, TO/MS	OW, OVM, TO/MS
23	OW, OVM, TO/MS	OW, OVM, TO/MS

[1]Describes oiling conditions for the majority of the oiled marsh platform; does not include the lower edge of the marsh characterized by SR/CV on the sediment, and vegetation “stubble”, which was not treated. Definitions: OW – heavily oiled wrack line (CT/TC), OVM – heavily oiled vegetation mat (CT/TC), TO –thick oil (> 1 cm), CV – oil cover (>0.1-1 cm), CT – oil coat (<0.1 cm), MS – mousse, SR – surface oil residue, TC – tarry consistency (on the vegetation).

5.5 Longer-Term Monitoring Results

The marsh treatment test plots were monitored monthly through September 2011. One monitoring period was missed in July 2011 for the October 2010 treatment plots due to several days of storm activity. There were no missed dates for the December 2010 treatment plots.

Oiling Conditions

Oiling conditions did not change dramatically across the plots over the duration of monitoring, other than the major change observed for the vegetation raking and cutting plots treated in December 2010. Average oiling conditions from September 2011 indicate the observed differences in conditions between the various treatments, 11 months (October 2010 treatments) and 9 months (December 2010 treatments) post-treatment (Table 3). Starting conditions in all the plots, other than the reference plots, were equivalent to the natural recovery plots.

Compared to the other treatments, vegetation raking and cutting resulted in the persistent removal of the oiled vegetation mat and wrack line and a lower distribution of oil on the sediment, predominated by surface oil residue rather than mousse. The remainder of the treatment plots did not change substantially over time, and were similar to the pre-treatment conditions documented roughly one year prior, including heavily oiled wrack, a continuous heavily oiled vegetation mat, and a continuous underlying layer of thick mousse on the substrate.

Table 3. Average summary oiling conditions for all treatments, September 2011[1].

Treatment	Oil Zones	Oil Sed. Distribution	Oil Sed. Thickness	Oil Sed. Character
October 2010				
Vegetation Raking[2]	OW, OVM, SED	Continuous	TO	MS
Natural Recovery (No Treatment)	OW, OVM, SED	Continuous	TO	MS
December 2010				
Vegetation Raking and Cutting	SED	Broken	TO (2 cm)	SR
Natural Recovery (No Treatment)	OW, OVM, SED	Continuous	TO (3 cm)	MS
Reference Plots				
Reference	NOO	NOO	NOO	NOO

[1]Describes oiling conditions for the majority of the oiled marsh platform; does not include the lower edge of the marsh characterized by SR/CV on the sediment, and vegetation "stubble", which was not treated. Definitions: OW – heavily oiled wrack line (CT/TC), OVM – heavily oiled vegetation mat (CT/TC), TO – thick oil (> 1 cm), CV – oil cover (>0.1-1 cm), CT – oil coat (<0.1 cm), MS – mousse, NOO – no oil observed, SED – oil on sediment surface, SR – surface oil residue, TC – tarry consistency (on the vegetation). [2]Combined Vegetation Raking, Raking-Flushing, Raking – Surface Washing Agent – Flushing, and Raking-Marsh Vacuum treatments.

Two oil re-mobilization events were also documented during the monitoring period. Severe storms coupled with high water levels in late April 2011 generated waves that caused localized re-mobilization of oil from the marsh platform (Figure 28). Monitoring conducted in early May 2011 documented oiling of new vegetation growth in the plots and oil pushed up to several meters further into the marsh by the storm, oiling the existing intact vegetation and establishing a new heavily oiled wrack line. Oil re-mobilization was greater for non-treated areas as compared to treated areas. New oil zones were described for oil on new vegetation growth in the plots, oil on the existing intact vegetation beyond the plots, and the new heavily oiled wrack line. Immediately after the monitoring period, under STR S3-045 (described below), the new oiled wrack line was removed from all areas except the natural recovery plots, limiting further oiling of vegetation and preventing much of the oil from reaching the substrate. In addition, all areas between the existing treatment plots were fully treated under STR S3-045 during May-June 2011. The new oil on the standing vegetation consisted of a coat to stain that persisted for roughly 2-3 months following the storm. The new vegetation growth in the plots generally survived this oiling event.

Figure 28. Localized remobilization of oil from the marsh platform, late April storm 2011. Top: new oiled wrack line and re-oiling of portions of the oiled vegetation mat. Bottom: remobilized oil on new vegetation growth within one of the plots (the vegetation survived). Photos from early May 2011.

Tropical Storm Lee in early September 2011 resulted in the second localized re-mobilization of oil from the marsh platform. In this case, the western end of the test area appeared to have experienced greater wave energy and oil remobilization, and there was a marked difference in the degree of re-mobilization between the vegetation raking and cutting plots (less to no remobilization) and the natural recovery plots (greater remobilization). There was little to no oil remobilization from the STR treatment areas between the plots. Oil remobilization from several of the natural recovery plots transported oil further into the marsh to tens of meters, oiling relatively patchy stands of *Juncus roemerianus* (black needlerush) vegetation that were not previously oiled (Figure 29). There was little to no oiling of other, more abundant marsh vegetation in the same vicinity, including *Spartina alterniflora* (smooth cordgrass) and *Spartina patens* (saltmeadow cordgrass). An oiled wrack line was not present and no oil was observed on the sediment. Tropical Storm Lee removed nearly all wrack lines, oiled and un-oiled, from the treatment test plots and reference plots.

Vegetation Recovery

Vegetation assessments were conducted monthly from June to September 2011. The main parameters were vegetation cover and plant species composition. The vegetation cover parameter only included new aboveground plant growth in the treatment test plots. All plots started with little to no living aboveground vegetation at the onset of the treatment tests, and they were dominated by heavily oiled dead plant stems that were either laid over (forming the oiled vegetation mat) or sloughed off, with only stubble remaining. Vegetation cover peaked during August 2011 across all treatments, though values were not very different over the other monitoring periods. Both the vegetation raking and the vegetation raking and cutting treatments had greater total vegetation cover than natural recovery (Table 4). The vegetation raking and cutting treatments showed the greatest vegetation cover (24%); four times greater than natural recovery (Figure 30). Total vegetation cover for the vegetation raking treatments (15%) was nearly two times greater than natural recovery. Total cover in the reference plots averaged 94%. In all the treatment test plots, most of the new vegetation growth originally emerged near the wrack line and the original limit of oiling in the upper plots, and seemed to slowly spread seaward with time. There was very little vegetation growth to date on the lower marsh edge.

Species composition in the treatment test plots was dominated by a variable mosaic of salt and brackish marsh species, including *Spartina patens*, *Paspalum vaginatum* (seashore paspalum), and *Distichlis spicata* (saltgrass) (Table 4). *Paspalum vaginatum* was often the first species that appeared in the plots as new growth. *Spartina patens* was a main dominant in the vegetation raking and the vegetation raking and cutting plots at the time of monitoring, but was not dominant in the natural recovery plots. Higher cover values within the natural recovery plots were typically due to *Paspalum vaginatum.* There was also some *Avicennia germinans* (black mangrove) seedling recruitment in the vegetation raking and cutting plots, but not in the other plots (Figure 31). One test plot also contained a patch of *Phragmites australis* (common reed), which had been present in the same area prior to the spill.

Figure 29. Localized remobilization of oil from the marsh platform, Tropical Storm Lee, September 2011. Oil from a natural recovery plot spread deeper into the marsh, oiling black needlerush, but not other vegetation species or the substrate.

Figure 30. Vegetation response following heavy oiling and treatment tests, August 2011. Top: natural recovery. Bottom: raking and cutting treatment in December 2010.

Figure 31. Mangrove seedling recruitment in the raked and cut plots, April 2011.

Table 4. Average vegetation characteristics for all treatments, August 2011[1].

Treatment	Total Vegetation Cover (%)	Dominant Species
October 2010		
Vegetation Raking[2]	15	SPA PAT, PAS VAG, DIS SPI
Natural Recovery (No Treatment)	8	PAS VAG, DIS SPI
December 2010		
Vegetation Raking and Cutting	24	SPA PAT, PAS VAG
Natural Recovery (No Treatment)	6	PAS VAG, DIS SPI
Reference Plots		
Reference	94	SPA ALT

[1]Definitions: SPA PAT – *Spartina patens*, PAS VAG – *Paspalum vaginatum*, DIS SPI – *Distichlis spicata*, SPA ALT – *Spartina alterniflora*. [2]Combined Vegetation Raking, Raking-Flushing, Raking – Surface Washing Agent – Flushing, and Raking-Marsh Vacuum treatments.

The reference plots were strongly dominated by *Spartina alterniflora*, with some *Juncus roemerianus* typically present, as well as *Spartina patens* and *Distichlis spicata*. Both *Spartina alterniflora* and *Juncus roemerianus* were originally present and appeared to be dominant prior to the spill in the treatment test plots, based on the appearance of the oiled vegetation mat and the intact vegetation landward of the oiled zones. The treatment test plots did have some *Spartina alterniflora* cover, but there was little to no *Juncus roemerianus* re-growth. New *Spartina alterniflora* growth in the treatment test plots often appeared stressed (displaying chlorosis, brown leaf tips, etc.), whereas *Spartina patens, Paspalum vaginatum*, and *Distichlis spicata* typically appeared to be in relatively good condition. *Paspalum vaginatum* was the only dominant species from the test plots that was not present in the reference plots.

Based on the vegetation monitoring results to date, including time-series photography, it appeared that the marsh vegetation was in a state of early recovery, more than a year following the original oiling and, in the treated plots, nearly one year post treatment. It also appeared that the vegetation raking treatments, and especially the vegetation raking and cutting treatments, aided early vegetation recovery. Furthermore, it does not seem that the vegetation raking or raking and cutting treatments caused further vegetation damage in addition to the oil spill, relative to natural recovery.

<u>Marsh Fauna</u>

Field notes on marsh intertidal macro-invertebrates and their field sign (burrows, feeding balls, tracks, etc.) were qualitatively recorded during the field visits and monitoring periods. *Armases cinereum* (squareback marsh crab) was frequently recorded across all the test plots (including no treatment) and reference plots throughout the duration of the tests and monitoring, even during the initial treatments in October 2010. At times, this species appeared to be quite abundant, even underneath the heavily oiled vegetation mats and wrack, emerging during raking operations. *Uca* spp. (fiddler crabs) first appeared in the treatment test plots in numbers in June 2011, when small burrows and crabs were noticed on the marsh surface (prior to this date, they were largely absent from the heavily oiled areas). Fiddler crabs and their burrows were present continuously in the reference plots, including prior to June 2011. *Littoraria irrorata* (marsh periwinkle) were nearly entirely absent from the treatment test plots, but were continuously present in numbers in the reference plots. *Geukensia demissa* (ribbed mussel), *Melampus bidentata* (eastern melampus snail), *Sesarma reticulatum* (purple marsh crab), and a marsh clam (likely *Polymesoda caroliniana*, Carolina marsh clam) were recorded in the reference plots, but no living individuals were located in any of the treatment test plots. *Geukensia demissa* appeared to have occurred in the treatment test area in roughly similar densities prior to the spill, based on the presence of empty shells attached to the bases of dead plant stems. *Littoraria irrorata*, *Melampus bidentata*, and *Sesarma reticulatum* also all occur landward of the treatment test plots, in marsh areas just beyond the extent of oiling.

During the September 2011 monitoring period, fiddler crab burrows (mainly *Uca longisignalis*, Gulf marsh fiddler crab, and *Uca spinicarpa*, spined fiddler crab) (Figure 32) and *Littoraria irrorata* snails were counted in three 0.25 m^2 quadrats in each plot, one each near the seaward marsh edge, the middle of the plot, and in the former late April 2011 wrack line at or just beyond the upper limit of each plot (near the limit of initial oiling and vegetation impact). The quadrat counts were pooled for purposes of comparison in this report. The vegetation raking and cutting plots and the reference plots, each had similar densities of fiddler crab burrows (Table 5), roughly three times greater than burrow densities in the vegetation raking plots and the natural recovery plots. Marsh periwinkles were nearly absent from all the treatment test plots, but were relatively abundant by comparison in the reference plots. Marsh periwinkles in the test plots were only recorded in low numbers in a few quadrats near the limit of initial oiling and vegetation impact.

Table 5. Average marsh fauna densities for all treatments, September 2011.

Treatment	Fiddler Crab Burrows	Marsh Periwinkles
October 2010		
Vegetation Raking[1]	5/m^2	0/m^2
Natural Recovery (No Treatment)	6/m^2	0/m^2
December 2010		
Vegetation Raking and Cutting	15/m^2	0/m^2
Natural Recovery (No Treatment)	5/m^2	0/m^2
Reference Plots		
Reference	17/m^2	37/m^2

[1]Combined Vegetation Raking, Raking-Flushing, Raking – Surface Washing Agent – Flushing, and Raking-Marsh Vacuum treatments.

Figure 32. Fiddler crab burrows and a captured individual from the treatment test plots, September 2011.

Based on the marsh fauna observations and data, it appears that some of the larger marsh invertebrates were also in a state of early recovery, particularly in terms of the intertidal crab fauna. Though the qualitative abundance of *Armases cinereum* across the treatment test area and the measured densities of fiddler crab (*Uca* spp.) burrows in the vegetation raking and cutting plots appeared similar to the reference plots, crabs were more commonly observed on the marsh surface in the reference plots, and oiled and dead crabs were frequently observed in the treatment test area. It also appeared that the vegetation raking and cutting treatments may have aided fiddler crab recruitment and persistence in heavily oiled areas, compared to all other treatments and natural recovery. In addition, it does not seem that the vegetation raking or raking and cutting treatments caused further damage to the crab fauna in addition to the oil spill, relative to natural recovery. In contrast, there appeared to be no signs of early recovery for marsh periwinkles in the treatment test area to date.

<u>Oil and Sediment Chemistry</u>

Surface oil and sediment samples were collected for chemical analysis pre- and post-treatment within the treatment test plots. Surface oil samples were collected from visually obvious oil layers scooped or scraped from the marsh surface. Sediment samples were collected from a 0-10 cm sediment core taken below the surface oil layers (not including the surface oil). Longer-term post-treatment samples were collected in late July and early August 2011 and are summarized below and in Table 6 (surface oil) and Table 7 (sediments).

The surface oil samples contained from 9-41% oil by weight. The densities ranged from 1.0 to 1.4 grams/milliliter (g/mL), indicating that the samples contained a large amount of sediment (the density of the fresh oil is 0.85 g/mL). The highest water content of the surface oil samples was 12%, indicating that much of the water content of the original mousse (which was reported as containing up to 60-80% water) was no longer present.

Total petroleum hydrocarbons (TPH) were reported on the analytical spreadsheets representing the sum of the n-alkanes from C9-C40 (Tables 6 and 7). Total aromatics for the oil samples were taken from the reported “Aromatics, Total” on the analytical spreadsheets, which appears to represent the total polynuclear aromatic hydrocarbons (PAHs) for which a value was reported (Table 6). For many of the PAHs for the oil samples, the results were reported only as <8,000 milligrams per kilogram (mg/kg); these “not quantified” values were not included in the “Aromatics, Total” sum. The total PAHs for the sediment samples are the sum of 45 PAHs as reported on the analytical spreadsheets (Table 7).

For the surface oil samples, TPHs and Total Aromatics were relatively similar across treatment types, including natural recovery (Table 6). Values were typically lower for treated areas versus natural recovery for each test period, though differences were not statistically significant.

Table 6. Average surface oil chemistry results for all treatments, July-August 2011[1].

Treatment	Surface Oil – TPH[2] (mg/kg)	Surface Oil - Total Aromatics[2] (mg/kg)
October 2010		
Vegetation Raking[3]	278,889	828
Natural Recovery (No Treatment)	311,111	833
December 2010		
Vegetation Raking and Cutting	334,000	505
Natural Recovery (No Treatment)	350,000	818
Reference Plots		
Reference	N/A	N/A

[1]Includes surface oil samples (oil on the sediment surface) in the middle of the oiled marsh platform, characterized by heavily oiled vegetation mats and underlying thick mousse on the sediment surface prior to treatment; does not include the lower marsh edge characterized by surface oil residue and vegetation "stubble", which was not treated. [2]TPH = total petroleum hydrocarbons; Total Aromatics = total polynuclear aromatic hydrocarbons (PAHs) for which a quantified value was reported, but not including many PAHs that were not quantified. [3]Combined Vegetation Raking, Raking-Flushing, Raking – Surface Washing Agent – Flushing, and Raking-Marsh Vacuum treatments.

Table 7. Average sediment chemistry results for all treatments, July-August 2011[1].

Treatment	Sediment – TPH[2] (mg/kg)	Sediment - Total PAH[2] (mg/kg)
October 2010		
Vegetation Raking[3]	59,567	132
Natural Recovery (No Treatment)	78,333	260
December 2010		
Vegetation Raking and Cutting	75,600	220
Natural Recovery (No Treatment)	86,800	355
Reference Plots		
Reference	1,162	<1

[1]Includes sediment core samples (0-10 cm below [not including] surface oiling) from the middle of the oiled marsh platform, characterized by heavily oiled vegetation mats and underlying thick mousse prior to treatment; does not include the lower marsh edge characterized by surface oil residue and vegetation "stubble", which was not treated. [2]TPH = total petroleum hydrocarbons; Total PAH = total polynuclear aromatic hydrocarbons. [3]Combined Vegetation Raking, Raking-Flushing, Raking – Surface Washing Agent – Flushing, and Raking-Marsh Vacuum treatments.

For the sediments samples, TPHs and Total PAHs were also relatively similar across treatment types, including natural recovery, and much lower for the reference plots in comparison (Table 7). Values were typically lower for treated areas versus natural recovery for each test period, though differences were not statistically significant. Importantly, these results indicate that neither TPHs nor Total PAHs in sediments below the surface oiling were greater in the treatment test plots as compared to natural recovery. That is, surface oil does not appear to have been pushed or mixed into the underlying sediments during treatment (by foot traffic for instance), as has been observed during past oil spills.

Oil weathering was examined using double-ratio plots for the PAHs C_2-phenanthrenes/C_2-chrysenes versus C_3-phenanthrenes/C_3-chrysenes. Chrysenes tend to weather more slowly than phenanthrenes; as the oil weathers, these ratios become smaller. In Figure 33, the surface oil samples are distributed in a linear trend from the upper right to the lower left of the graph, indicating an increasing degree of weathering. The surface oil samples from the lower marsh edge (Oiling Zone A series shown as circles, characterized as surface oil residue, $\leq$1 cm thick, that was not covered by the oiled vegetation mats and wrack), are more weathered than the oil samples from the middle oiled marsh platform (Oiling Zone B series shown as triangles, characterized as thick (>1 cm) mousse on the sediment surface underneath heavily oiled vegetation mats and wrack prior to treatment). Removal of the oiled vegetation mats and wrack and partial removal/breakup of the surface oil layer should enhance the weathering process.

Figure 34 shows a similar double ratio plot for the sediment samples. The trend is more linear, but the patterns are the same, as compared to the surface oil samples. That is, the samples from the sediments on the lower marsh edge are more weathered, compared to those from the middle of the oiled marsh platform. However, it seems that the residual oil in the sediments from the vegetation raking and cutting treatment (shown as red triangles) was more weathered (plotted closer to the lower left), than the natural recovery or vegetation raking plots. This is the first chemical evidence showing that raking and cutting improved the rate of weathering in the marsh soils.

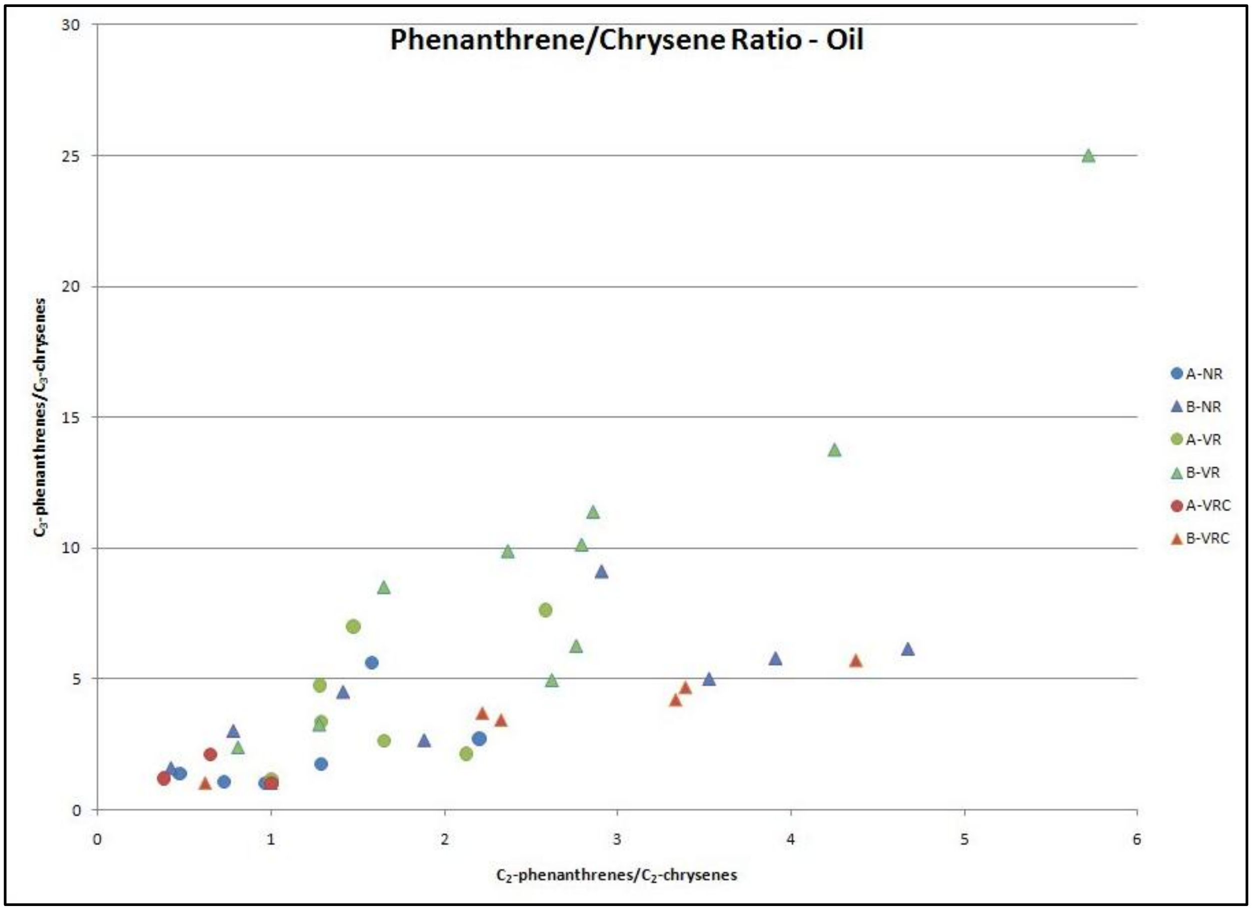


Figure 33. Double-ratio plot of C_2-phenanthrenes/C_2-chrysenes versus C_3-phenanthrenes/C_3-chrysenes for surface oil samples collected in late July/early August 2011, post-treatment. A = Oiling Zone A - exposed surface oil residue on the lower marsh edge, B = Oiling Zone B – thick mousse under vegetation mats/wrack in the middle of the oiled marsh platform (pre-treatment condition). NR = natural recovery (no treatment), VR = vegetation raking, VRC = more intensive vegetation raking and cutting.

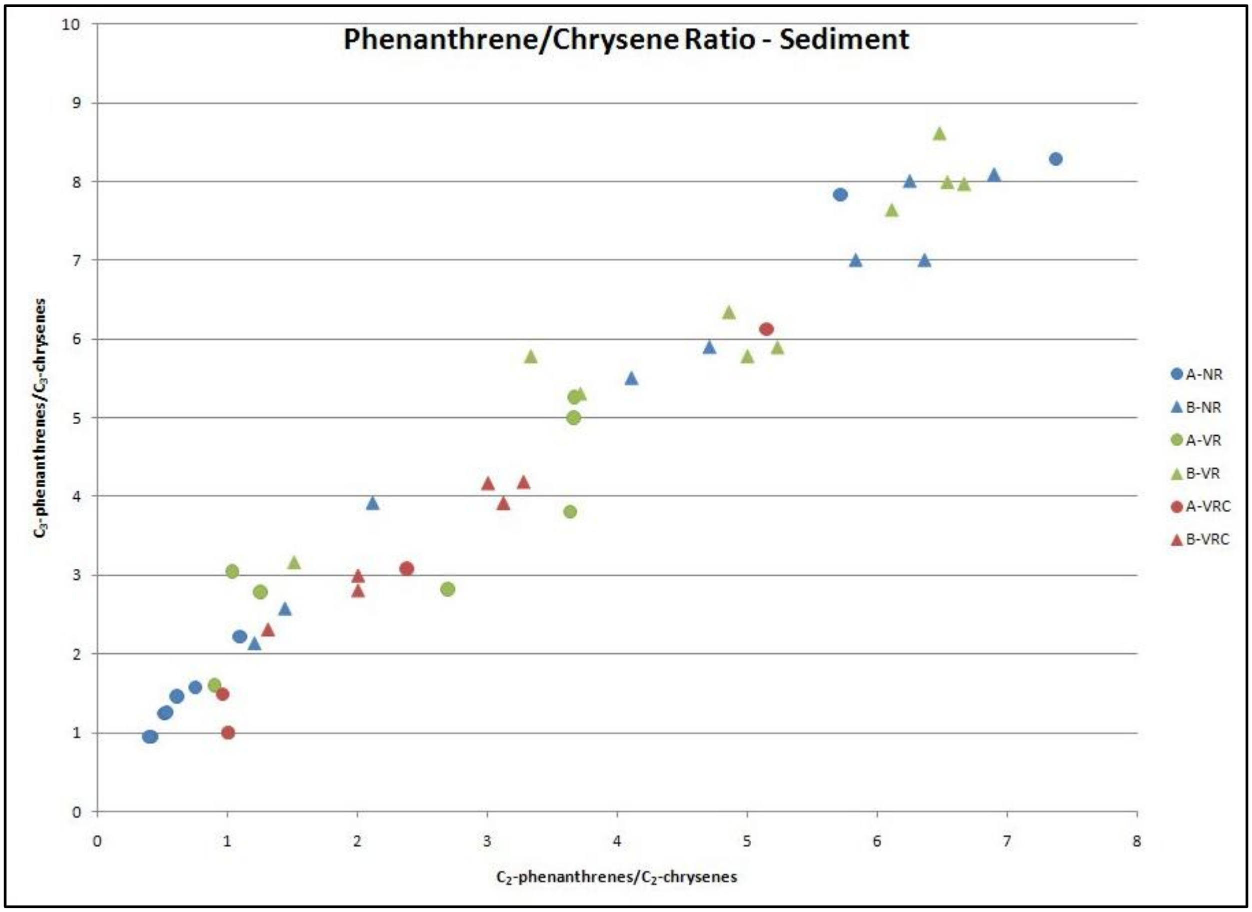


Figure 34. Double-ratio plot of C_2-phenanthrenes/C_2-chrysenes versus C_3-phenanthrenes/C_3-chrysenes in the sediment samples collected in late July/early August 2011, post-treatment. A = Oiling Zone A - exposed surface oil residue on the lower marsh edge, B = Oiling Zone B - thick mousse under vegetation mats/wrack in the middle of the oiled marsh platform (pre-treatment condition). NR = natural recovery (no treatment), VR = vegetation raking, VRC = more intensive vegetation raking and cutting.

6 Shoreline Treatment Recommendations (STRs)

6.1 Stage III - STR S3-045

Based on the treatment tests conducted in December 2010 and the early January 2011 monitoring results, a decision was made in coordination with the Unified Command to draft STR S3-045 based on the vegetation raking and cutting treatments. The STR was drafted in early January 2011 and circulated for review and approval. Following intense and lengthy review, including multiple agency meetings and site visits to the treatment test area, STR S3-045 was approved and issued in mid February 2011. The following paragraph from the STR provides important context,

> *"Cleanup recommendations under this STR are based on the Marsh Treatment Tests being managed by the SCAT Program and NOAA, with on-going involvement and input by the parish, state, and federal government agencies; the Unified Command, including Operations; the Regional Response Team (RRT); and others. State agency and parish representatives have been present during all treatment test operations and subsequent monitoring, have provided input and engaged in discussion, and are generally supportive of the proposed cleanup methods. It should be recognized by all stakeholders that there is inherent risk in both applying the treatment methods described below or in choosing a no-treatment alternative for these marshes (either alternatives could result in greater or continued marsh impact, with the potential for aggressive treatment to either enhance recovery or cause addition harm, the outcome of which is uncertain). Although recent monitoring (January 2011) has indicated that the proposed methods have been successful in removing the heavily oiled vegetation wrack, vegetation mat, and portions of the thick oil, and weathering the remaining oil, the proposed methods are considered aggressive and the response of the marsh vegetation (positive, negative, or neutral) will not be fully known until Spring or Summer 2011. The primary test participants agree, however, that due to the severity of oiling and the potential of the remaining oil to affect wildlife, the recent positive results of the treatment tests favor scaling to operational levels."*

The STR originally identified approximately 15 km (9 miles) of heavily oiled salt marsh in Northern Barataria Bay for potential treatment, based on SCAT survey data, field notes, and photographs collected between September 2010 and February 2011 (Figure 35). Other locations in Northern Barataria Bay with comparable oiling conditions could be treated under STR S3-045 as well, based on field reconnaissance and continuing SCAT surveys. Conditions targeted by this STR generally included: 1) heavily oiled vegetation mats; 2) heavily oiled high-water wrack lines; and 3) thick oil (mainly mousse) on the marsh surface or shallow subsurface. Weathered surface oil residues on the lower marsh edge were not recommended for treatment.

The treatment recommendations were built upon what was learned during the treatment tests and subsequent monitoring, adopting the vegetation raking and cutting methods and tools developed during the tests. In addition, based on post-test monitoring, additional treatment methods incorporated into the STR included carefully raking or scooping remaining pooled oil from the marsh surface following

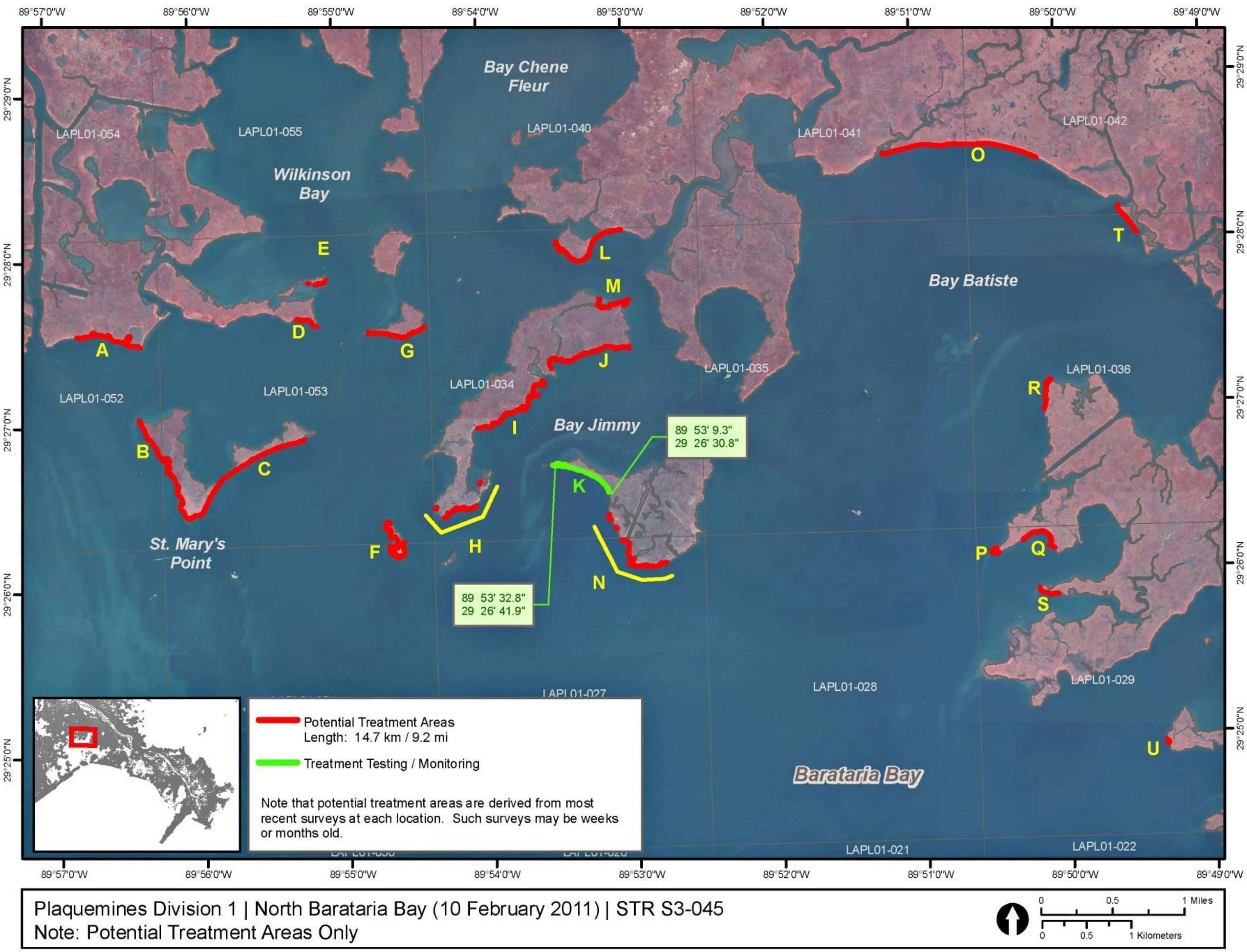


Figure 35. STR S3-045 potential treatment and test areas (zones).

vegetation raking and cutting (minimizing sediment removal), and applying loose organic sorbents (e.g., bagasse, kenaf) to the remaining pooled oil and then collecting the oiled sorbent material for disposal. Walk boards were required for all work on the marsh.

The STR incorporated an adaptive management theme, with the flexibility for refining and changing the treatments over time based on field conditions, treatment observations, and monitoring, including continued monitoring of the treatment test plots. Limited “set aside” or “no treatment” areas were an important part of this concept, for comparative purposes and for additional treatment testing, if needed. A scheduled duration (time limit) was set for the STR, with any continuing treatment requiring re-evaluation and a subsequent STR revision. The original STR duration spanned mid February to mid April 2011.

In addition, due to the sensitive nature of the marsh environment and the relatively intensive treatment methods being applied, SCAT/agency field advisors-monitors were required to be present during all treatment operations. The SCAT/agency advisors-monitors were comprised of personnel with backgrounds in salt marsh ecology. Their role was to work in close coordination with Operations in the field to recommend where to apply treatments, which components of the STR treatments to apply, the level or intensity of treatments to be applied, and when to pause or stop treatments. They consisted of personnel from SCAT, NOAA, Louisiana Department of Environmental Quality (LDEQ), Louisiana Office of Coastal Protection and Restoration (OCPR), Louisiana Department of Wildlife and Fisheries (LDWF), and BP.

A provision was made for low-impact mechanical equipment to potentially be used under the STR under certain conditions. Mechanical methods could be used if identified and capable of working within the guidelines, objectives, and Best Management Practices (BMPs) described in the STR, with improvements in effectiveness, efficiency, or lower levels of disturbance. Mechanical methods could be considered following an authorized demonstration conducted in coordination with the SCAT/agency field advisors-monitors, and upon their subsequent approval. However, if substantial changes in the STR were required to accommodate mechanical methods, a new or revised STR would be required.

Finally, the No Further Treatment (NFT) Guidelines for this STR were: (1) removal of the heavily oiled wrack line; (2) removal/elimination of the heavily oiled vegetation mats (including mats buried by fine organics or fine sediments); (3) raking down through any thick oil or mousse layers present beneath the oiled vegetation mats, to the depth of continuous oiling; (4) removal/reduction of thick accumulations of relatively fresh mousse or liquid oil from the marsh surface, which could include the eventual conversion of this oil to a predominance of weathering surface oil residue; and (5) removal of all response equipment and materials, sorbents, walking boards, waste, and the majority of walking board footprints (compacted areas) within the marsh.

6.2 STR S3-045 Revisions

Four revisions were issued for this STR, all with full Unified Command and agency approvals. Revision 1 (STR S3-045.r.1, issued in mid April 2011) included a time extension through May 2011, revised the sorbent boom guidelines in the STR, added information on mechanical demonstrations and operations, added treatment recommendations for heavily oiled shell material on the marsh platform, added guidelines for the use of loose organic sorbents without collection, updated the maps and coordinates for potential treatment areas based on field reconnaissance and additional SCAT surveys, and addressed other minor updates and clarifications.

Revision 1 included a short description of two mechanical approaches that were demonstrated and approved for use under the STR. The two approaches included barge- and airboat-based platforms with long-reach hydraulic arms coupled with attachments including rakes, grapples, vegetation cutting devices, and “squeegees” capable of working within the confines of the STR. The “squeegee” devices were used to reduce thick mousse on the surface of the marsh following vegetation raking and cutting.

During implementation of the STR, it was determined that the application of loose organic sorbents (bagasse, kenaf, etc.) as a final polishing step in the treatment process would be desirable in freshly treated areas, particularly to reduce potential wildlife exposure where freshly exposed oil remained on the substrate or vegetation. The loose organic sorbents would be left in place and not collected. SCAT and NOAA developed an RRT application to propose this treatment. RRT approval was received in early April 2011 and was incorporated into the STR revision.

Revision 2 (STR S3-045.r.2, issued in late May 2011) extended the STR dates to late July 2011. Revision 3 (STR S3-045.r.3, issued on 1 August 2011) extended the STR dates to the end of August 2011. Revision 4 (STR S3-045.r.4, issued in late August 2011) extended the STR date to mid September 2011. Minor additions and extensions to the potential treatment area maps were included in these revisions as needed.

6.3 Stage IV - STR S4-032

STR S4-032 was written to address patrol and maintenance treatments and re-current oiling once treatment areas reached NFT under STR S3-045. This STR was issued in mid July 2011. The potential treatment areas were the same as those under STR S3-045. The treatment recommendations included many of the same methods under the prior STR, but were generally less intensive and aimed at specific oiling conditions. Further intensive vegetation raking and cutting was not authorized. Likewise, most mechanical methods were not included.

The oiling conditions targeted by STR S4-032 included: (1) recoverable sheen, mousse, or liquid oil at the seaward edge of the marsh that was mobilizing to the water surface or threatening to mobilize to the water due to high temperatures, sunlight exposure, or shoreline erosion; (2) surface patches of thick relatively continuous mousse or liquid oil that re-developed on the marsh platform post-treatment; (3) thick mousse or liquid oil seeping from the landward edges of treatment areas where the intact, living marsh vegetation was not treated; and (4) residual oil on the marsh that was remobilized by storm events, forming heavily oiled wrack lines where mousse or liquid oil saturates or heavily coats the majority of the wrack materials, and where mousse or liquid oil was spreading to the live marsh vegetation or substrate, or potentially exposing wildlife to oil.

The NFT Guidelines for STR S4-032 were: (1) removal of recoverable sheen, mousse, or liquid oil mobilized or mobilizing to the water surface from the marsh edge, or minimization of this oiling to levels as low as reasonably practicable considering the approved treatment methods and net environmental benefit considerations; (2) removal of thick relatively continuous mousse or liquid oil on the marsh platform, or minimization to levels as low as reasonably practicable considering the approved treatment methods and net environmental benefit considerations; (3) removal of heavily oiled wrack lines (as described above) following storm events that re-mobilize mousse or liquid oil; and (4) removal of all response equipment and materials, including sorbent boom, walking boards, etc. associated with the STR from the marsh at the completion of each treatment application (excluding loose organic sorbents applied as specified under RRT and STR approvals).

7 Operational Treatments

7.1 STR S3-045

Operational treatments were conducted under STR S3-045 from mid February to mid September 2011, a seven-month period (Schneider *et al*., 2011). SCAT/agency advisors-monitors were present during all operations. All treatment zones were inspected by SCAT and met the STR-specific Stage III NFT criteria upon completion of the STR. Treatments included both manual and combined mechanical-manual approaches. Treatments varied by location according to the type and degree of oiling conditions. All the STR treatment types described above were applied in some locations; other sites only required partial treatments, such as heavily oiled wrack removal. The most heavily oiled sites were STR Zones B (cove only), G, H, I, J, K, and N. These areas, as well as others, received the full suite of STR treatments, including follow-up treatments in some cases. All locations treated under STR S3-045 are depicted in Figure 36. A total of 24 km (15 miles) of potential treatment areas were identified. Roughly 11 km (7 miles) of marsh shorelines were treated; 6,429 cubic yards and 536 tons (1,072,000 lbs) of oil and oiled vegetation/debris were removed by Operations under this STR.

Manual treatments were used in all treatment areas and consisted of workers on walk boards applying the STR using hand tools and power hedge trimmers. Mechanical treatments were conducted from April to June 2011. Mechanical treatments included barge-based and large airboat-based platforms positioned in waters adjacent to marsh treatment areas (Figure 36). In each case, mechanical operations used long-reach hydraulic arms coupled with attachments including grapples, rakes, cutting devices, and “squeegees” to conduct marsh treatments (Figure 37). The “squeegee” devices were used to skim thick mousse from the surface of the marsh following the removal of heavily oiled wrack and vegetation mats. Mechanical work was always followed by manual treatment to complete the STR, typically in close succession.

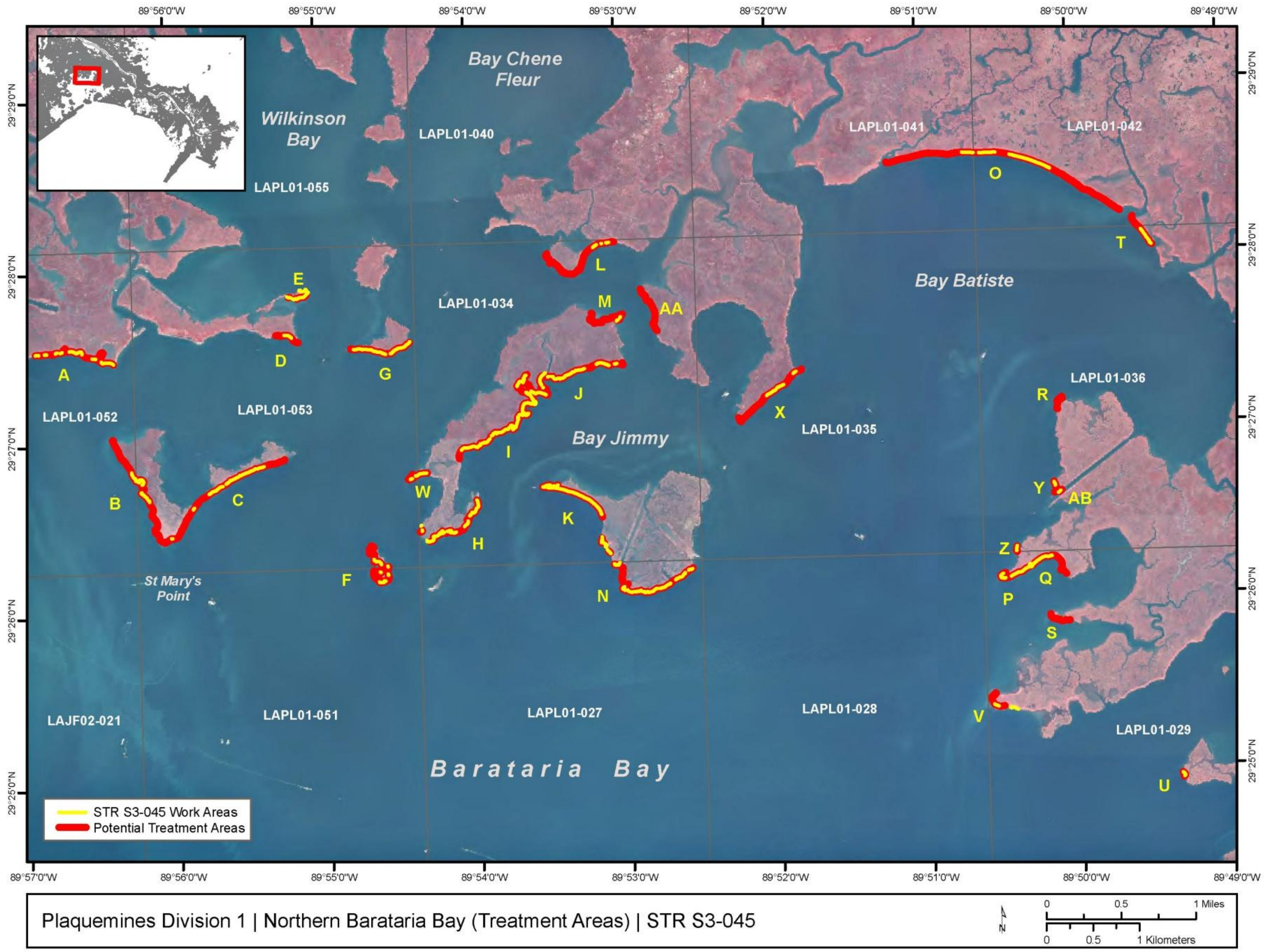


Figure 36. STR S3-045 treatment areas (yellow) and final potential treatment zones (red).

Figure 37. Mechanical treatment platforms. Top: barge, long-reach track hoe with hydraulic grappler, and roll-off containers. Bottom: large airboat with vegetation cutting tool.

Figure 38. Mechanical tools (examples). Top: raking attachment (barge crew). Bottom: mousse squeegee device (airboat crew).

Although the mechanical treatments provided increased efficiency in some cases, the manual treatments were considered more effective for marsh treatment. Mechanical treatments were particularly efficient and effective for heavily oiled wrack removal and for waste handling at the completion of treatments, removing oiled vegetation/debris from the marsh directly into roll-off containers or super-sacks. Mechanical treatments also contributed to other aspects of the STR treatment sequence, including removal of the oiled vegetation mats and mousse layers; however, manual teams were often more precise in this regard. Although the mechanical treatments had greater potential for marsh disturbance, and did cause gouging of the marsh substrate, mixing of oil into the sediments, or excess removal of marsh sediments in some areas, close coordination between the mechanical crews, the SCAT/agency field advisors-monitors, and Operations supervisors minimized marsh disturbance. Overall, the preferred treatment approach under similar circumstances would be to maximize the number of small, well-supervised manual treatment teams, using a limited number of mechanical teams for rapid oiled wrack removal and to support oiled waste handling.

Winter and early spring months were considered the most desirable and effective treatment seasons for several reasons. First, the marsh vegetation was largely dormant during this period, so vegetation disturbance was less of a concern, and there was less living aboveground vegetation growth encountered. Secondly, the oil was easier to handle and could be removed more effectively during colder temperatures, when it was in a semi-solid state. Because the oil was less fluid, there was also reduced concern that oil or sheens could be mobilized to other marsh areas or adjacent waters during treatment. Also, daytime low tides and wind-driven low water levels were more conducive for treatments during this time period, when the marsh platform was exposed for long periods. Storm activity was also reduced during this time, resulting in fewer stand-down days and work stoppages, as compared to the summer months, when daily thunderstorm activity was prevalent (though there were a few stand-downs in winter due to cold temperatures and the passage of northern storm fronts). Finally, the lower daytime air temperatures during this period allowed more comfortable and efficient working conditions for the manual crews, resulting in greater work production and limiting safety concerns related to heat stress, sun exposure, and dehydration. Regarding seasonality, the preferred treatment approach under similar circumstances would be to maximize treatment operations during winter and early spring, and where possible, complete treatments prior to the summer months.

As the STR treatments progressed into late spring and summer growing seasons, in many locations, “new” vegetation growth began emerging or growing through the oiled vegetation mats. Oiled vegetation mats and thick mousse could not be as effectively treated due to this vegetation. In addition, when raking was conducted in these areas, it was immediately noticed that the new growth would frequently be uprooted, pushed over, and oiled during raking, which was considered detrimental to vegetation recovery. Where new growth was present, it was decided that cutting should be attempted prior to raking and removal of the oiled vegetation mats and underlying thick mousse. Cutting this vegetation allowed treatment to proceed without uprooting or otherwise damaging the new growth. In addition, the cut vegetation was observed to almost immediately resume rapid shoot growth following treatment. After careful consideration, where heavy oiling was present, particularly the thick mousse layer, cutting of the new vegetation growth was included as part of the treatment sequence. Vegetation cutting of new growth was constantly re-evaluated and discussed, with the intent to limit activities that could reduce or slow vegetation recovery, balancing this with the removal of thick mousse still present on the marsh substrate. Mid September 2011 was set as the maximum time period beyond which cutting of new growth would no longer be authorized, to allow time for the vegetation to translocate aboveground production into belowground plant reserves during late summer and fall, prior to the on-coming winter months. No detrimental results of cutting were observed during the treatment period or immediately thereafter, and new vegetation growth to full plant height was the typical post-treatment condition. In most cases, this vegetation could not be differentiated from adjacent marsh areas.

Similar to what was described for the treatment tests, two storm-driven oil remobilization events occurred during the STR treatments. Severe storms coupled with high water levels in late April 2011 generated waves that caused localized remobilization of oil from the marsh platform. Oil was pushed up to several meters further into the marsh by the storm in many locations across the STR area, oiling bands of existing intact vegetation and establishing new heavily oiled wrack lines. Oil remobilization was greater for non-treated versus treated locations across the STR area. Comparisons of treated locations with adjacent "set-aside" areas (such the Natural Resource Damage Assessment [NRDA] study sites) and areas yet to be treated indicated more severe oil remobilization and subsequent marsh oiling in the areas not treated. Following the storm, new heavily oiled wrack lines were rapidly removed across the STR area by both mechanical and manual teams, successfully limiting further oiling of vegetation and preventing much of the oil from reaching the sediments.

Tropical Storm Lee in early September 2011 resulted in the second localized remobilization of oil from the marsh platform. There was little to no oil remobilization from areas that were treated under the STR. As before, areas that had not been treated had greater oil remobilization and subsequent marsh oiling as compared to areas where STR treatments had been applied. Oil re-mobilization following this storm resulted in oiling of standing intact vegetation, as well as the scattering of oil mixed with fine organic material ("coffee grounds") across a few marsh locations near small coffee-ground-dominated "pocket beaches" that were broken up by the storm. Heavily oiled wrack lines were not formed, and little to no oil reached the marsh substrate. Tropical Storm Lee removed many wrack lines across the STR area, including un-oiled wrack. No obvious signs of increased erosion were noted as a result of the STR treatments, as compared to non-treated areas. Following both these storms, set-aside locations (no treatment areas) were important for comparative purposes, as they validated the success of the STR treatments in reducing the degree of oiling and preventing or reducing oil remobilization from marshes across the STR area.

7.2 STR S4-032

Patrol and maintenance operations under STR S4-032 were continuing at the time of this report (October 2011). Roughly 5-10 patrol visits had been made per each STR zone into October 2011, with treatment activities so far limited to STR Zones F, J, L, N, O, Q, X, and AA. The majority of work had taken place in Zone J (nearly 6,000 lbs of oil and oiled vegetation debris removed), Zone N (over 1,000 lbs removed), and Zone Q (over 1,500 lbs removed). Agency monitors from LDEQ assisted Operations with patrol and maintenance recommendations, in coordination with SCAT. Patrols indicated that much of the area appeared to have been effectively treated with the completion of STR S3-045; however, it was thought that additional intensive treatments could be needed in several areas, pending future SCAT surveys, field reconnaissance, and STR revisions, as appropriate.

8 Set-Asides and Other Studies

At the time of this report, the Unified Command and several associated programs and organizations were evaluating several groups of “set-asides” or “no treatment” sites, to determine their future status (Figure 38). Questions included whether or not they should be treated (where needed), moved out of the response, and/or retained for future monitoring and research. As stated above, set-asides (including the treatment test plots) had been very useful for determining the efficacy and effects of STR treatments. If retained, the set-asides would also be valuable for evaluating oiling conditions, treatment alternatives, cleanup response, habitat recovery, and restoration measures over the longer term, contributing to a better understanding of this event and enhancing response and restoration capabilities for future spills. Most of these sites were associated with planned or on-going studies by other organizations, particularly several universities. A brief overview of the various set-asides and other related studies are provided below.

8.1 Marsh Treatment Test Plots

The marsh treatment test plots (Zone K), described above in greater detail, included nine natural recovery plots and nine to fourteen plots that could be considered partially treated, in that the test methods applied were not as extensive as the full STR treatments. Five of the fourteen plots included the manual raking and cutting treatments that formed the basis of the STR, and were similar to the STR treated areas. There were also five nearby reference plots associated with the treatment tests, each containing very light to no oiling. Each test plot consisted of ~6 m (20 feet) of linear shoreline. Complete mechanical and manual STR treatments were applied between each plot, and heavily oiled wrack from the April 2011 storms was removed from all the plots. NOAA expressed interest in retaining the plots in their existing condition for continued monitoring and research. Louisiana State University (LSU), Tulane University, Nicholls State University (NSU), and University of California Berkeley have also expressed interest in conducting further research using the existing test plots. LSU had conducted limited preliminary sampling in the plots.

8.2 NRDA Study Sites

The NRDA program had 14 set-aside stations within the STR S3-045 and S4-032 areas that are associated with on-going NRDA studies. Each of the NRDA set-aside stations consisted of 100 m (330 ft) of linear shoreline that were excluded from STR treatments. In addition, the NRDA program has 14 other study sites specifically set-up in treated STR areas (to look at potential treatment effects). The NRDA program also has a number of other study sites established throughout various marsh locations in Louisiana, including other sites in Northern Barataria Bay located outside of STR shoreline segments. NOAA expressed interest in using the set-aside and associated sites for continued monitoring and research at the conclusion of NRDA studies.

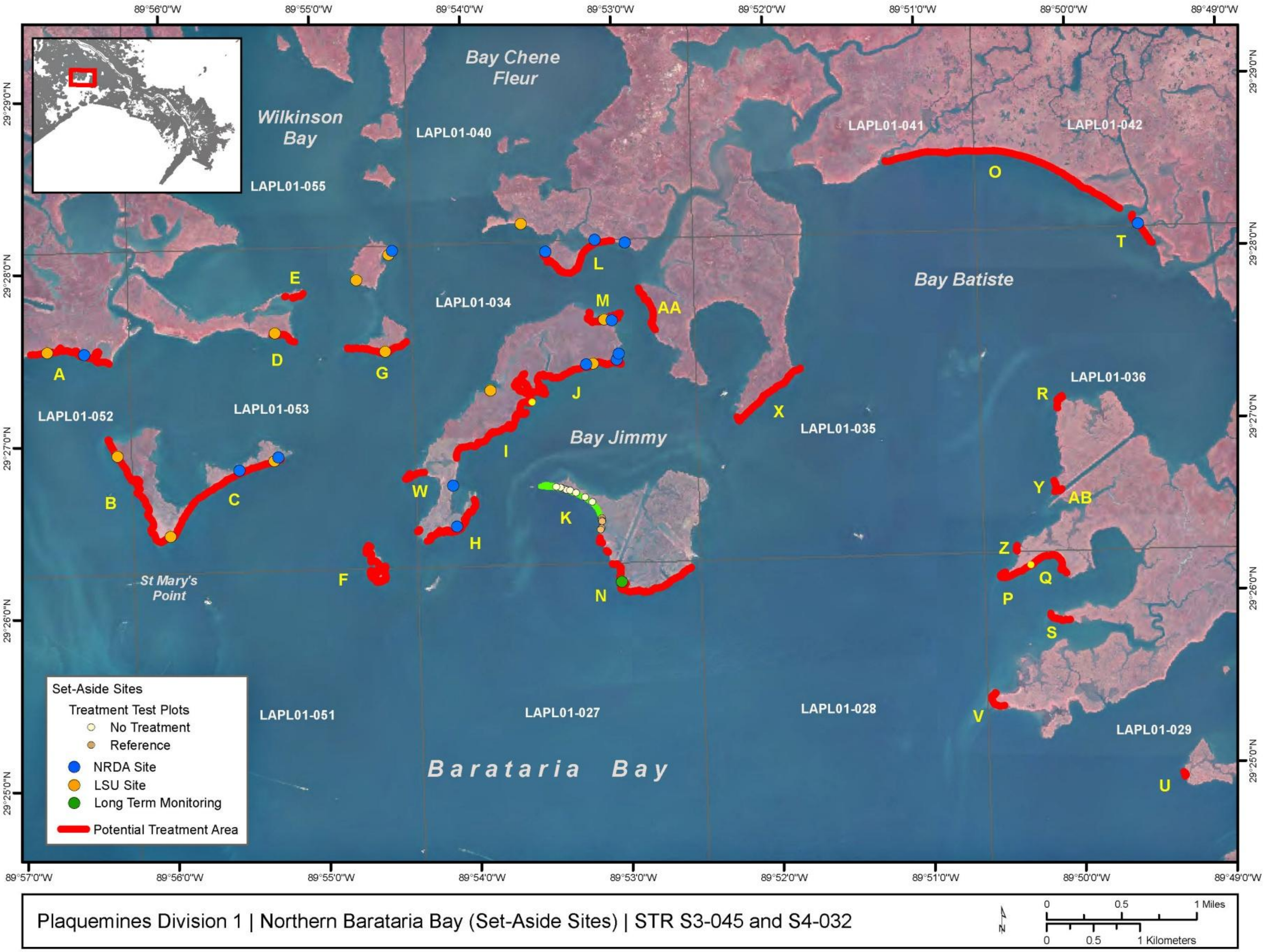


Figure 39. Map of set-aside (no treatment) locations.

8.3 LSU Study Sites

LSU had 12 set-aside stations within the STR S3-045 and S4-032 areas that are associated with on-going university studies, funded by Gulf Research Initiative (GRI) awards specific to the *Deepwater Horizon* event. Each of the LSU set-aside stations consists of 40 m (132 ft) of linear shoreline that were excluded from STR treatments. In addition, LSU has a number of other study sites established throughout various marsh locations in Louisiana, including other sites in Northern Barataria Bay located outside of STR shoreline segments. LSU has on-going research plans for the various sites they have established. NOAA has expressed interest in collaborative monitoring and research in these areas as well.

8.4 Environmental Unit Long-Term Set-Asides

The Environmental Unit has one set-aside site located in the Northern Barataria Bay marshes. This site had been periodically sampled for oil and sediment chemistry by BP. The sampling program for this site was completed in October 2011.

8.5 Tulane/NSU Marsh Planting Study

Tulane and NSU are conducting a marsh re-planting study in small plots located in between and adjacent to the existing marsh treatment test plots described above (Zone K). Each Tulane/NSU plot includes 5 m (16.5 feet) of linear shoreline. Prior to the onset of the study, their plots were treated under STR S3-045 and met NFT guidelines. Tulane and NSU are examining different marsh planting methods and comparing the performance of different *Spartina alterniflora* varieties for marsh restoration in heavily oiled and treated areas (Figure 39).

9 Summary and Recommendations

9.1 Overall Evaluation of the Treatment Tests

The treatment tests were valuable in that they allowed standardized, replicated comparisons of a variety of potential treatment options: 1) over the short-term, directly supporting treatment decisions and STR development; and 2) over a year or more afterward, tracking vegetation response and other parameters, as well as storm-driven oil re-mobilization events, via periodic monitoring. The tests immediately ruled out most treatment options, and even supported the decision to cancel one existing STR and related operations that were ineffective and potentially damaging to the marsh (STR S3-008, marsh vacuum treatments). Through short-term monitoring, the tests also ruled out vegetation raking alone, which initially was thought to have potential as a stand-alone treatment, and was advocated by some for immediate scaling to operational levels. The subsequent vegetation raking and cutting treatments formed the basis for the development of STR S3-045, which was applied to roughly 11 km of shoreline. Continued monitoring also led to STR improvements over time. Monitoring also provided information regarding longer-term effectiveness and effects of the various methods nearly one year post-treatment. Monitoring indicated that the treatments that formed the basis of the STR did not cause greater damage to the marsh or hinder marsh recovery, but actually enhanced recovery as compared to other methods, including no treatment. Finally, the natural recovery (no treatment) and partial treatment plots allowed useful comparisons with the STR treatments, indicating that the STR treatments

Figure 40. Tulane/NSU marsh planting study plots with planted *Spartina alterniflora* in area treated under STR S3-045, Zone K, November 2011.

minimized storm-driven oil remobilization and further marsh oiling. The treatment test plots, including the no-treatment plots and other set-asides, if retained, would be valuable for determining the longer term efficacy and effects (positive or negative) of marsh cleanup operations conducted during this incident.

9.2 Overall Evaluation of the STR Treatments

The STR S3-045 treatments were successful at removing or reducing very heavy oiling conditions in the marsh, while also enhancing the weathering and degradation of oil that remained. Most importantly, it appears that the appropriate balance was struck: the STR treatments were intensive enough to be effective, without being too aggressive and causing excessive disturbance or additional widespread marsh damage. The lack of oil remobilization and re-current oiling in the STR treatment areas during recent storms, as compared to similar areas that had not been treated, coupled with no obvious indications of increased erosion resulting from the treatments alone, further indicates that the treatments were effective and appropriate. The diligent and careful work of the Operations teams, including the constant use of walk boards on the marsh and the involvement of the SCAT/agency field advisors-monitors, working closely with Operations everyday on the marsh, were critical in striking this balance. In terms of improvements, a greater emphasis on maintaining sufficient numbers of manual teams coupled with supporting mechanical tools would likely have been the best approach. More rapid decision-making, including timelier STR review and approval, as well as completing the STR treatments more rapidly, may have allowed work in the marshes to be concluded earlier, allowing for a longer post-treatment growing season. Finally, it should be emphasized that the marsh oiling conditions encountered in the STR treatment areas were substantial and persistent. The intensive manual and mechanical methods used, including vegetation raking and cutting, would not be appropriate for the majority of oil spills in salt marsh environments, and in many cases, could potentially result in further marsh damage and limit marsh recovery. Even during this spill, only the most heavily oiled salt marshes were intensively treated; a small fraction (~1%) of the 795 km of marsh shorelines that were oiled across the Gulf States. Natural recovery was the preferred and appropriate approach for the vast majority of oiled marshes.

9.3 Next Steps

Recommended future actions include: 1) continued review of STR S4-032 patrol and maintenance reports from Operations and LDEQ; 2) Shoreline Clean-up Completion Plan (SCCP) surveys and inspections and/or post-hurricane season SCAT surveys and field reconnaissance to be conducted in November-December 2011 for all STR S4-032 zones, segments, and adjacent areas, as appropriate, to determine the need for any further treatment; and 3) retention of set-asides for continued monitoring and research to evaluate oiling conditions, treatment alternatives, cleanup response, habitat recovery, and restoration measures over the longer term, contributing to a better understanding of this event and enhancing response and restoration capabilities for future spills.

Priority areas for upcoming SCAT surveys and field reconnaissance would include locations that were the most heavily oiled (STR Zones B, G, H, I, J, K, and N), as well as any current set-aside sites that will not be retained for future monitoring and research. Any further intensive treatments (e.g., raking and cutting) should be limited to areas where such treatment would be critical for long-term marsh recovery and restoration, taking net environmental benefit and “as low as reasonably practicable” oiling levels under careful consideration. If areas requiring intensive treatments similar to STR S3-045 are identified, STR S4-032 could be modified accordingly, subject to agency and Unified Command approval. Intensive treatments should require the continual presence of SCAT/agency advisors-monitors similar to operations under STR S3-045. It is recommended that any additional intensive treatments be delayed until 15 December 2011, and initiated and completed as rapidly as possible thereafter during the winter months, using manual crews. Following the completion of subsequent surveys and STR S4-032 operations, including any additional intensive treatments, this report should be updated.

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